Positron source for SuperKEKB

and self-introduction

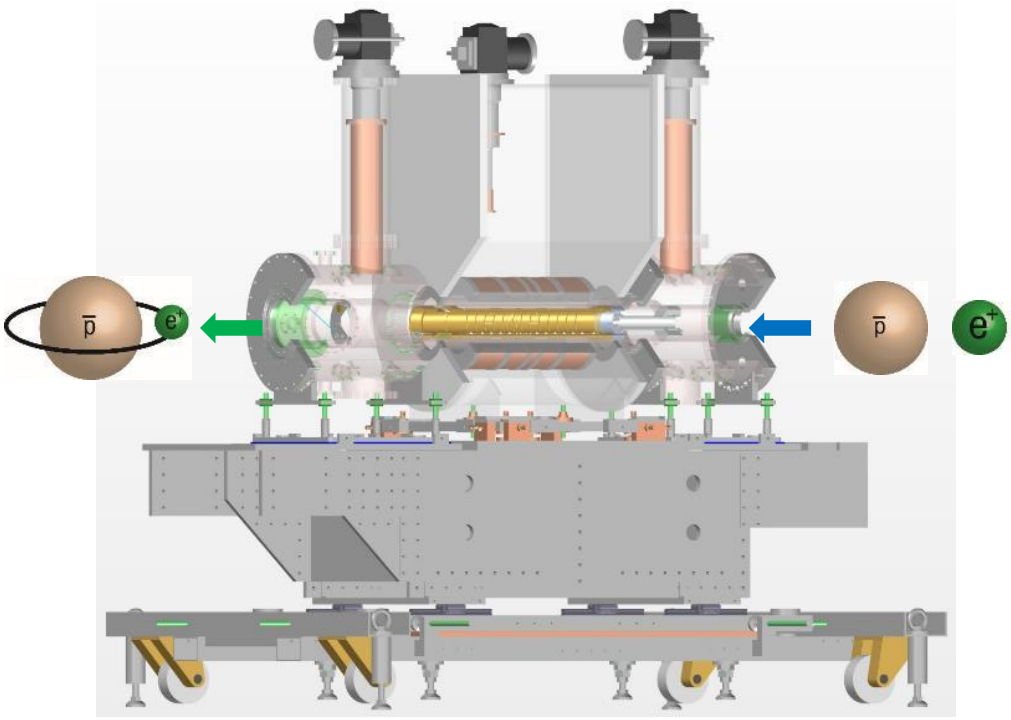
2022/10/24

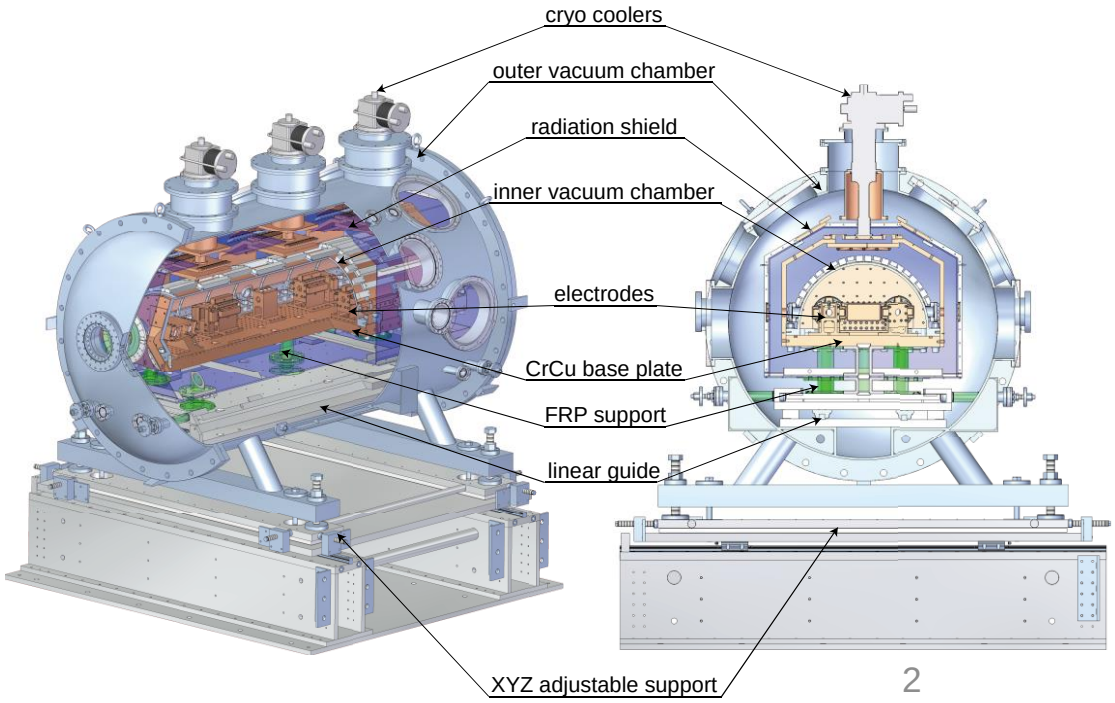
Yoshinari ENOMOTO

Research career

period	Affiliation	site	field	Thema
2005-2011	U. Tokyo	CERN (AD)	Atomic physics Plasma physics	Synthesis of cold antihydrogen in a cryogenic charged particle trap
2011-2015	Riken	Riken	Atomic physics Molecular physics	Cryogenic electrostatic ion storage ring
2015-	KEK	KEK (Tsukuba)	Accelerator	Positron source Magnet power supply

Physic analysis << hardware design and manufacturing





	Project	Y. E.
～2010	KEKB	
2011	SuperKEKB construction started	
2011/3	Large earthquake	
2015/4		Joined SuperKEKB project
2016	Phase 1 started (＜ 1 nC)	
2018	Phase 2 started	
2018/6		ALCW@Fukuoka
2019	Phase 3 started	
2019/10		LCWS@Sendai
2020	Major upgrade of positron source (～3.5 nC)	
2021/3		LCWS online
2022/9		Joined ILC project

Topics

- From 1 nC to 3.5 nC
  - Solve discharge problem of FC
    - Change material of FC head
    - External circuit to reduce voltage
  - Improve beam handling
    - Install steering coils inside the solenoid
- Toward 4 nC and above
  - Shorten distance between FC and 1st acc. Structure
- Another topics
  - Rotating target
  - Full model simulation
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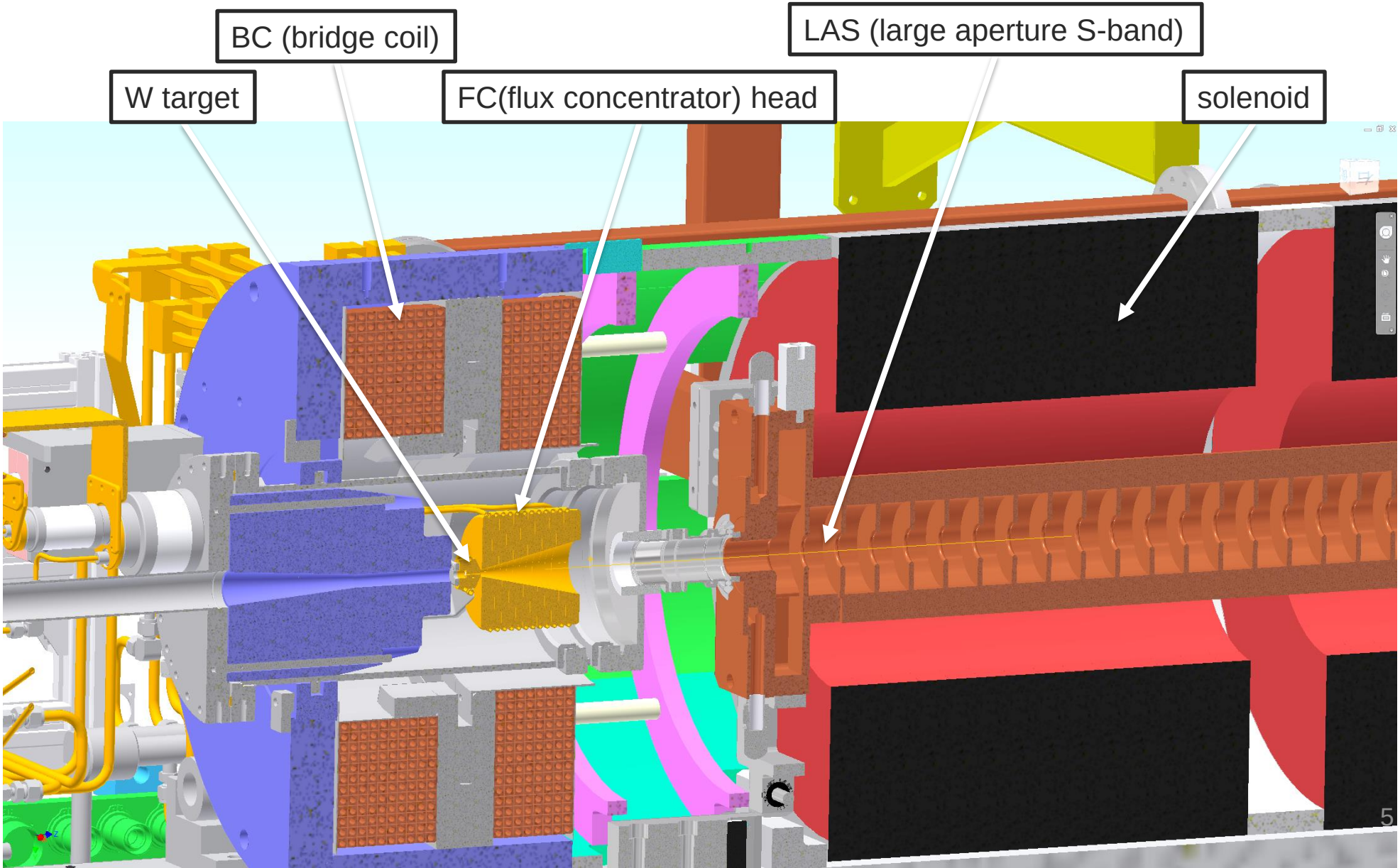
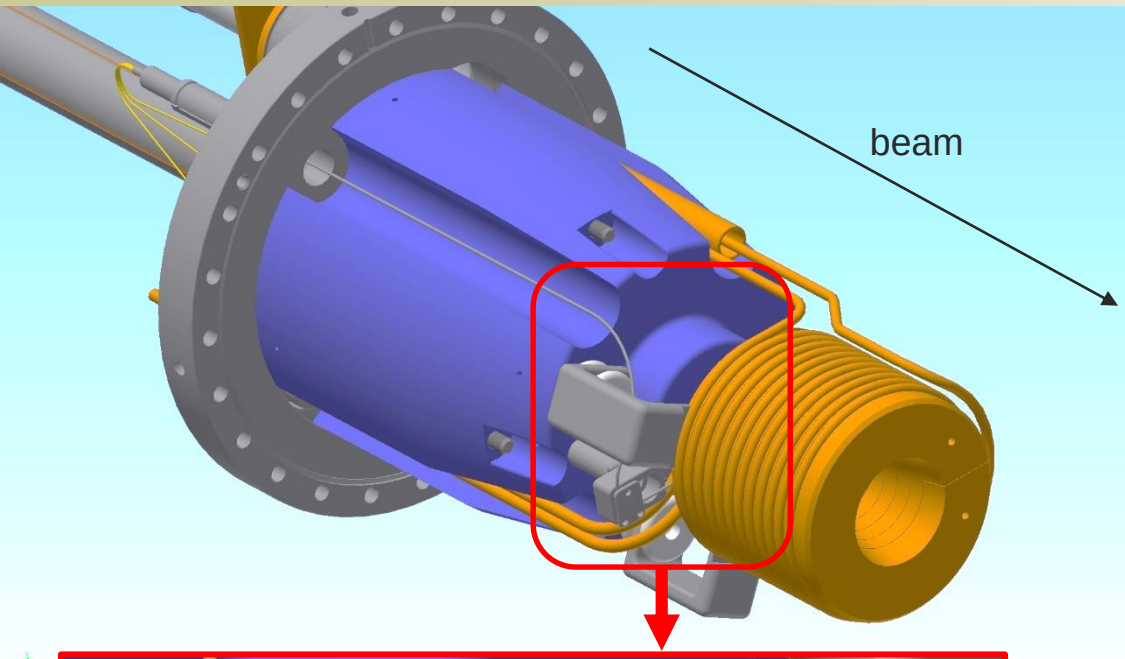
  - Evaluation of W and W-Cu connection

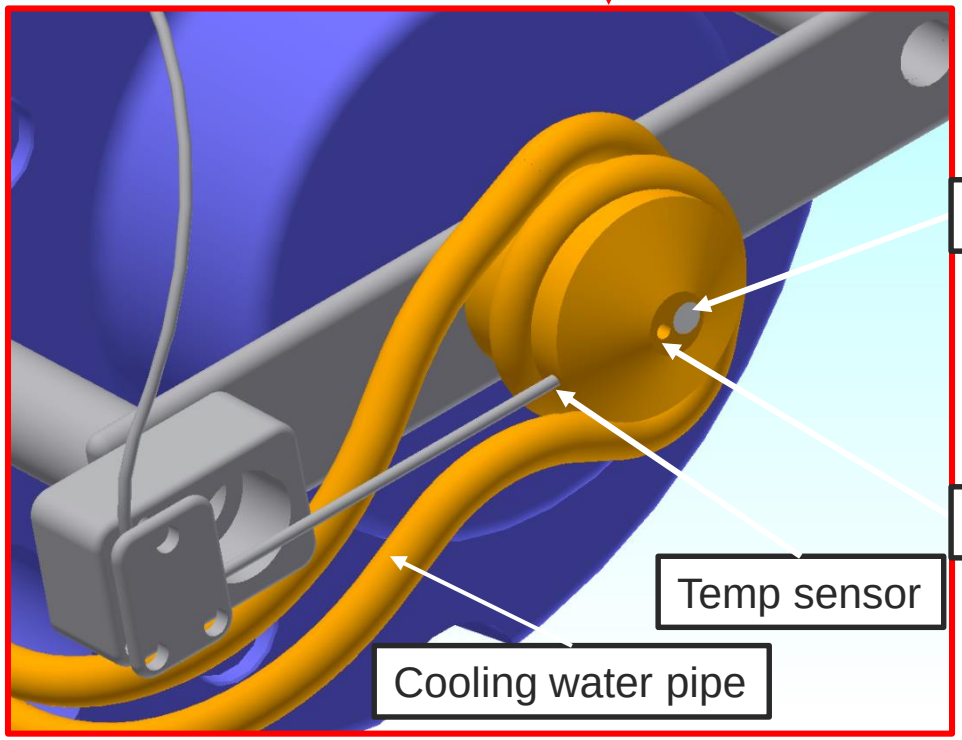
SuperKEKB positron source 1

FC head + BC + target = FC assembly



SuperKEKB positron source 2



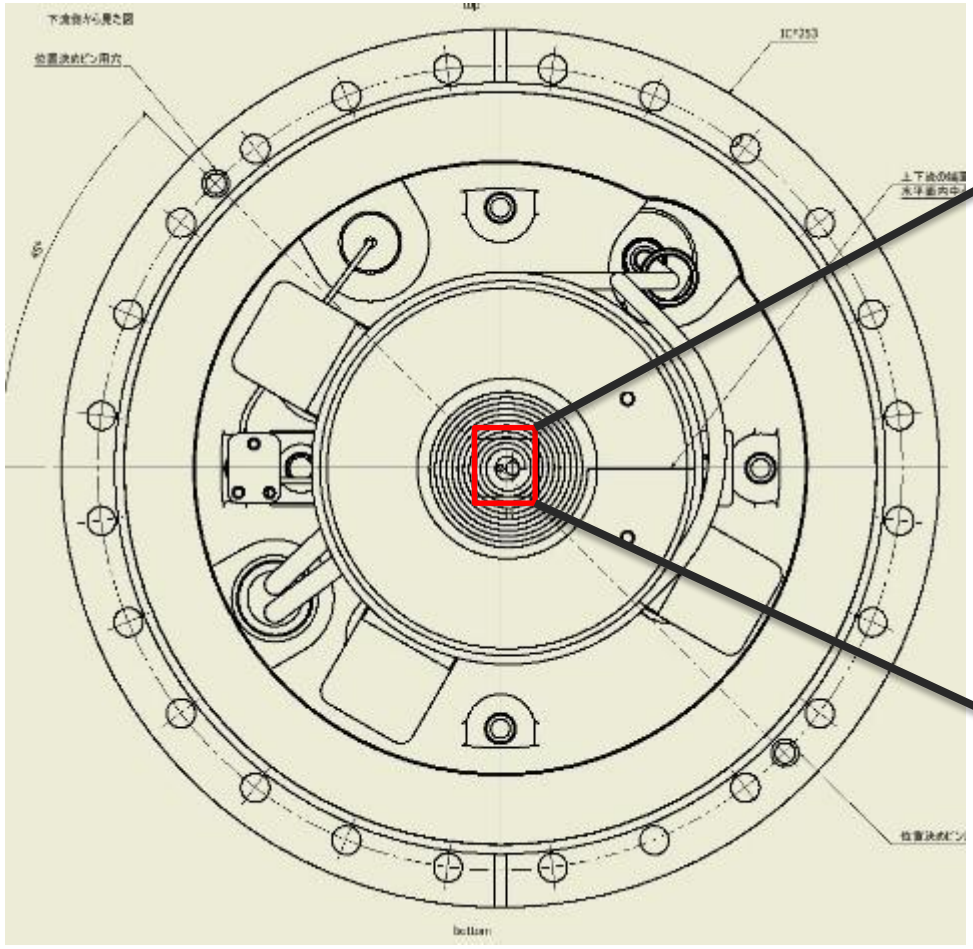


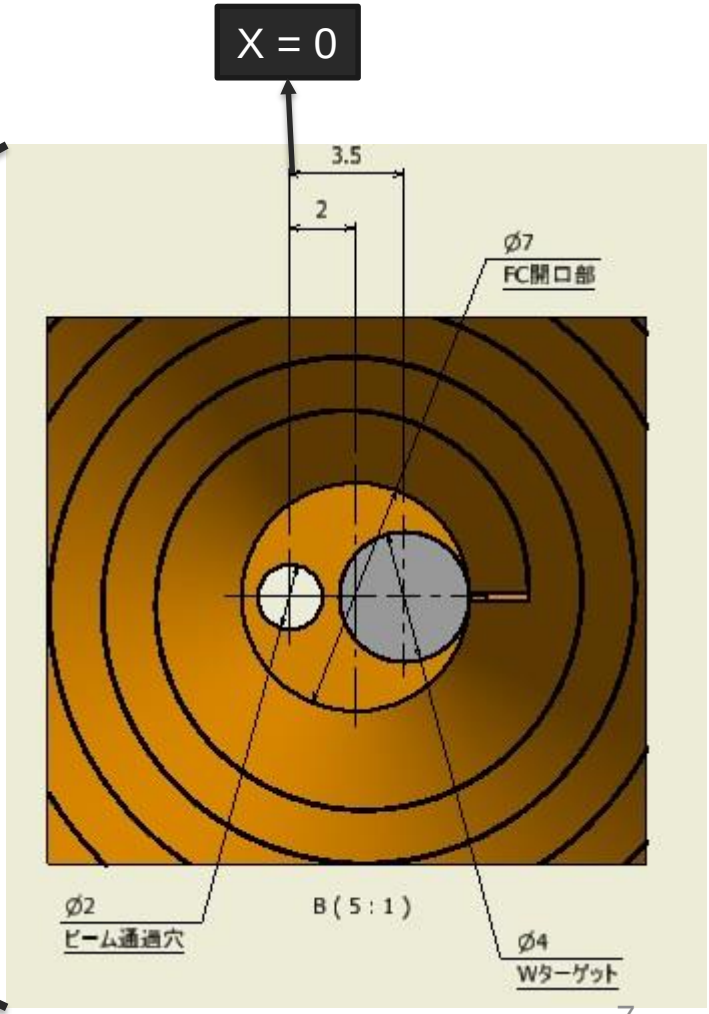
SuperKEKB positron source 3

Target material : W
Target size : Φ4 x 14
Inserted in the pule Cu block
Connected by HIP process

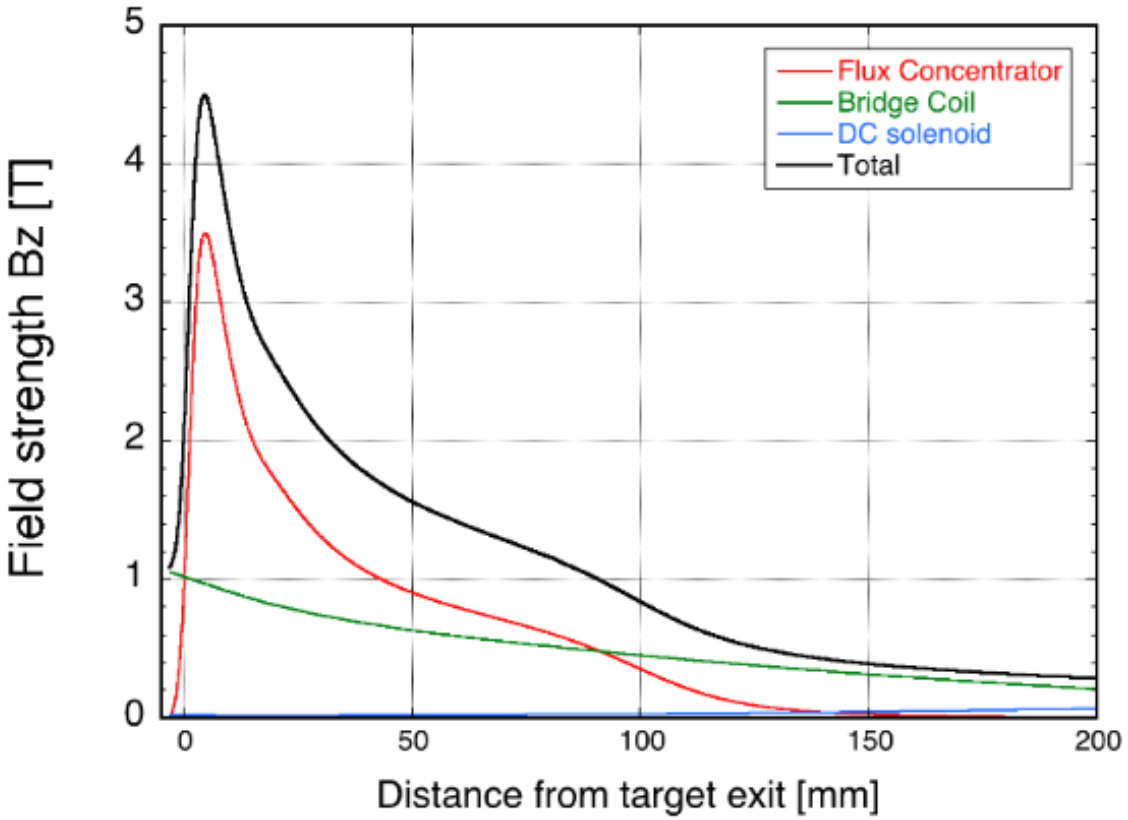
looking from downstream side

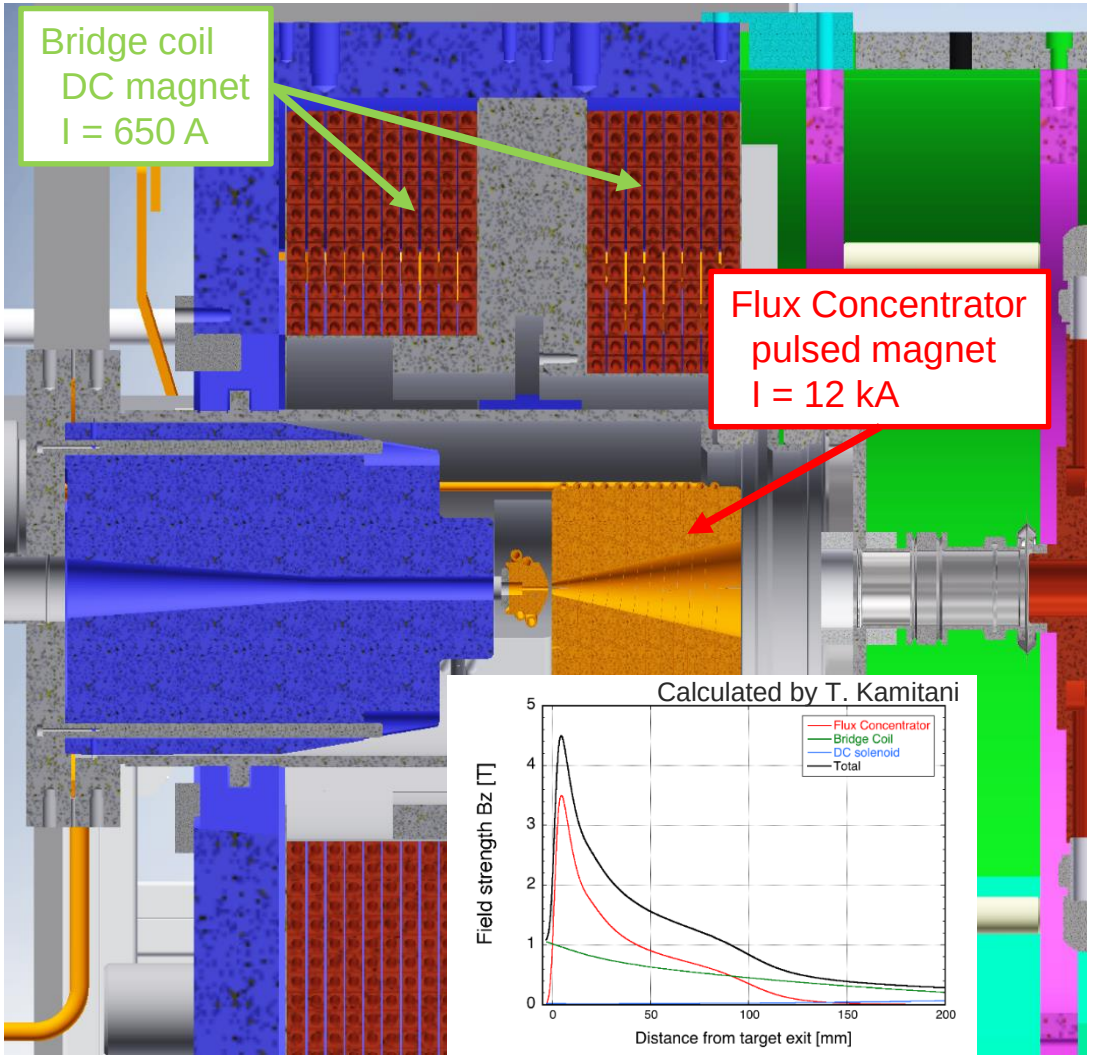
X = 0 hole for electron
X = 2 center of the FC
X = 3.5 center of the W target





SuperKEKB positron source 4





Ratio B @ target / B @ entrance of the LAS is important
stronger field is preferred in the following solenoid section
much stronger field is required @ target

Injection requirement

Life in ring	360 s
Current	3.6 A
Injection bunch charge	4 nC
Injection rate	25 Hz x 2 bunch
Injection efficiency	50 %
Circulation frequency	10^5

$$\frac{dI}{dt} = \frac{3.6\ [\mathrm{A}]}{360\ [\mathrm{s}]} = 10\ [m\mathrm{A/s}]$$

$$4\ [\mathrm{nC}] \times 25\ [\mathrm{Hz}] \times 2\ [\mathrm{bunch}] \times 50[\%] \times 10^5[\mathrm{Hz}] = 10\ [m\mathrm{A/s}]$$

Short storage time and high storage current in the ring
→high intensity positron injection is desired

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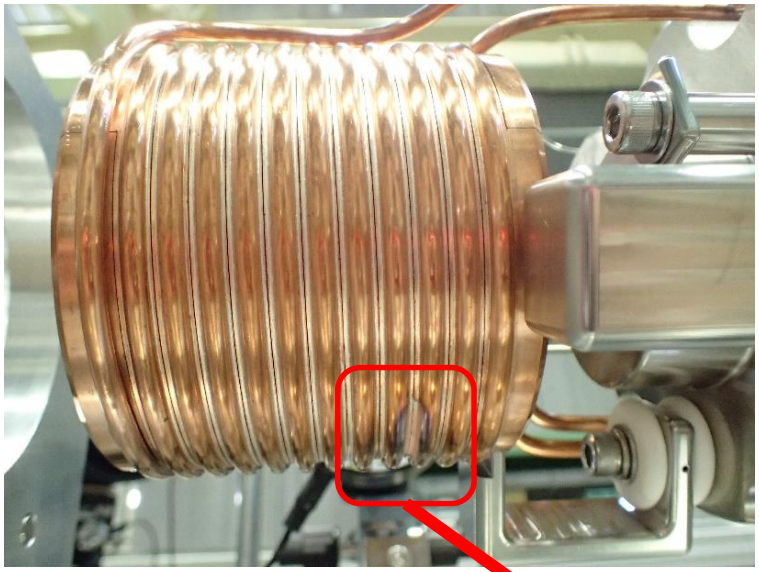
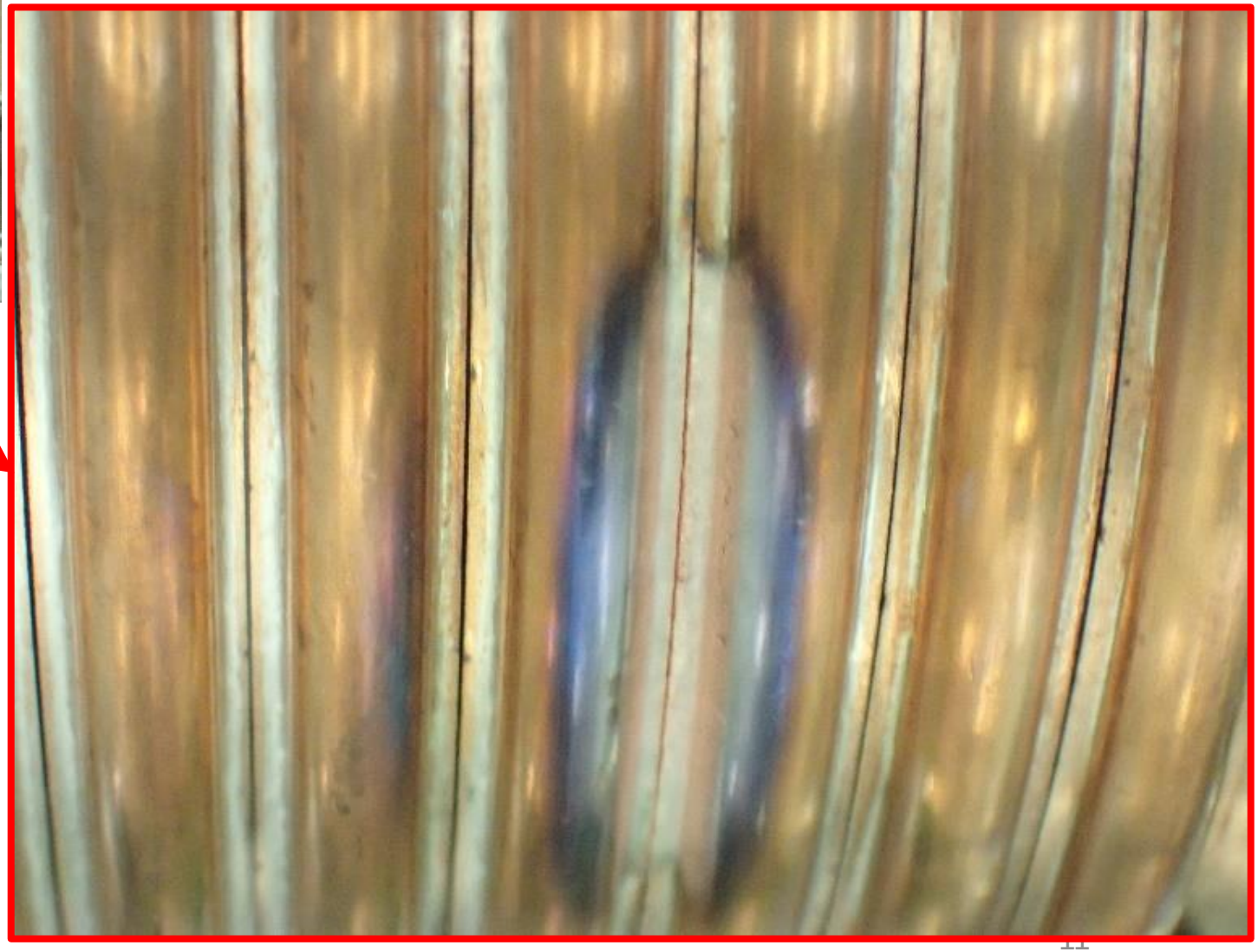
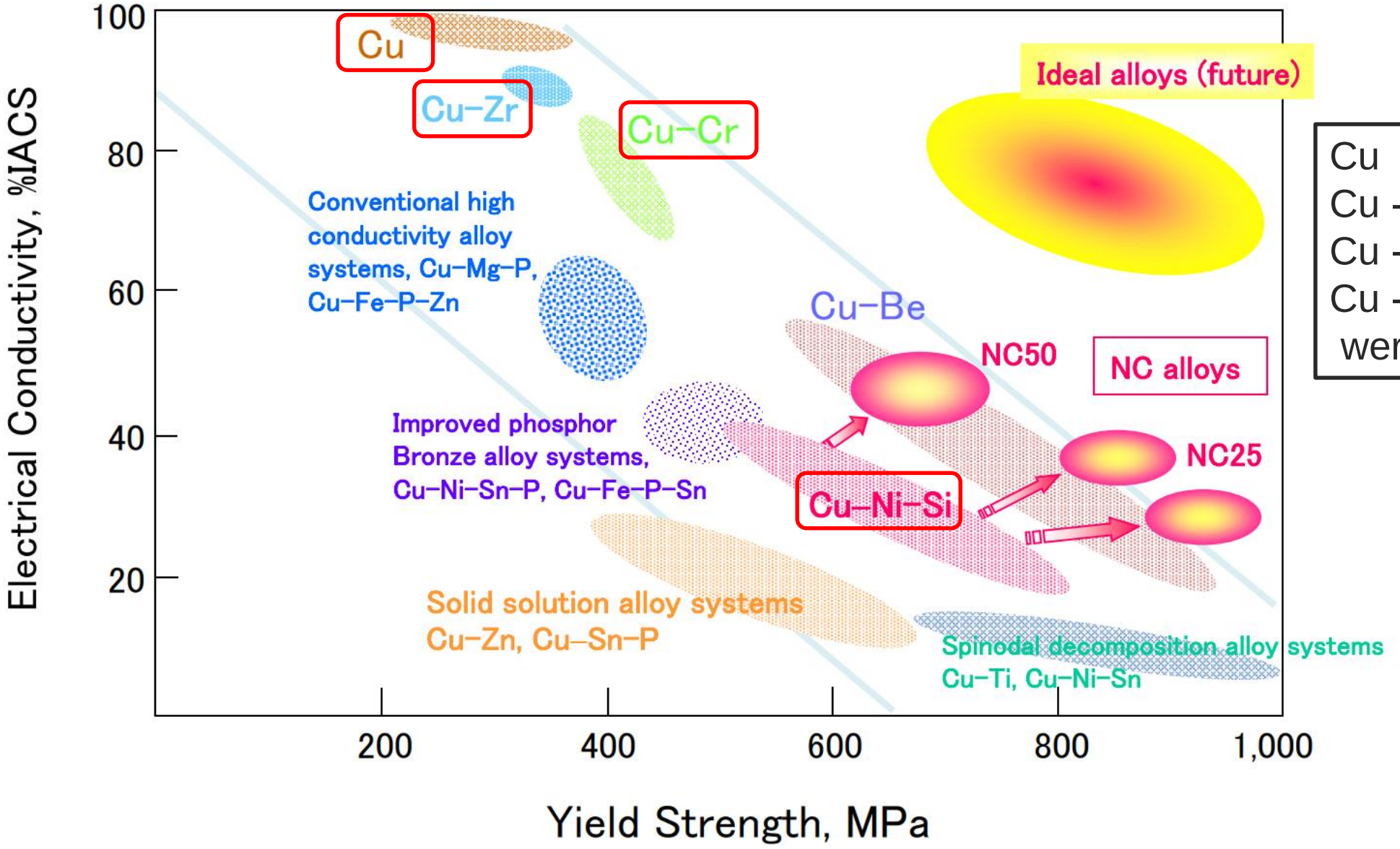
After large discharge…





Slit gap got narrow.
Not possible to apply high voltage unless the gap will be expanded.

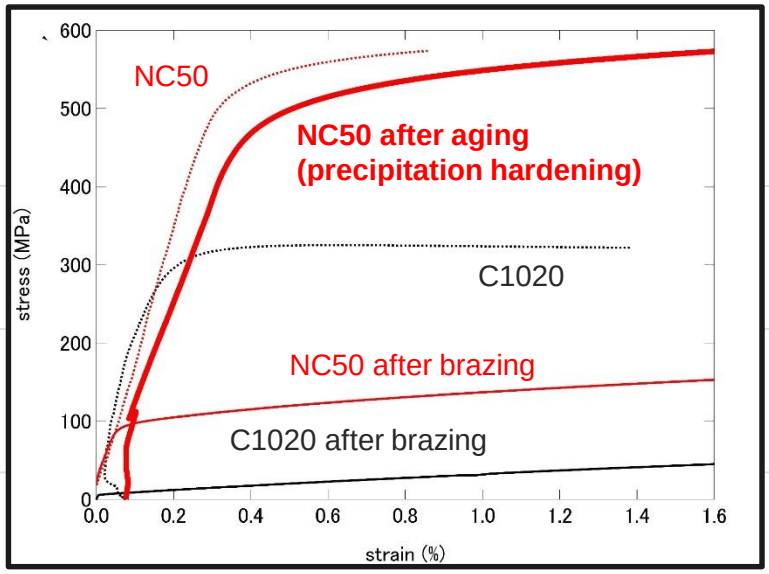
Cu alloys



Positions of various copper alloy systems in conductivity–strength map

Cu
Cu - Zr
Cu - Cr
Cu - Ni - Si
were tested

Yield strength



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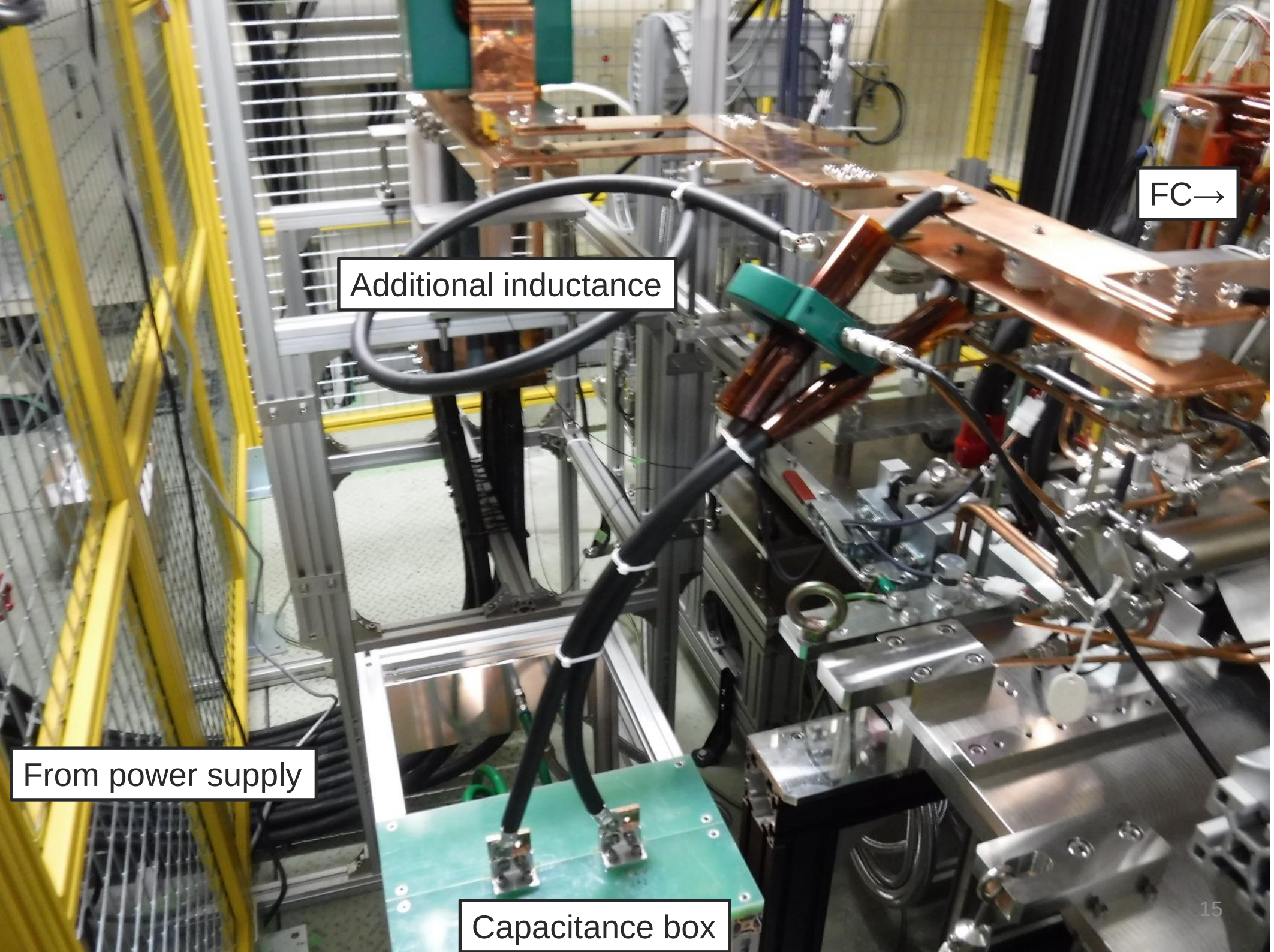
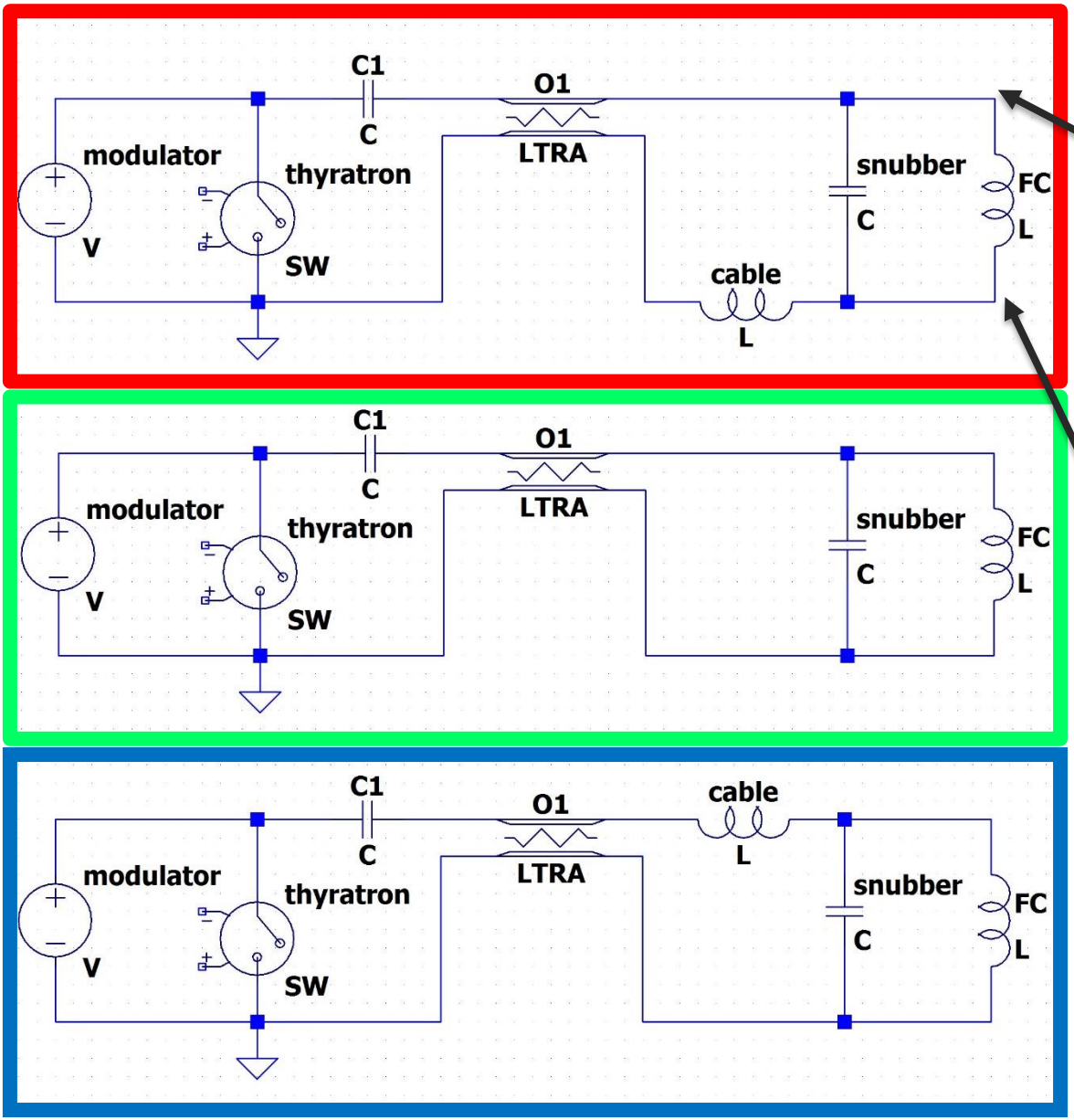
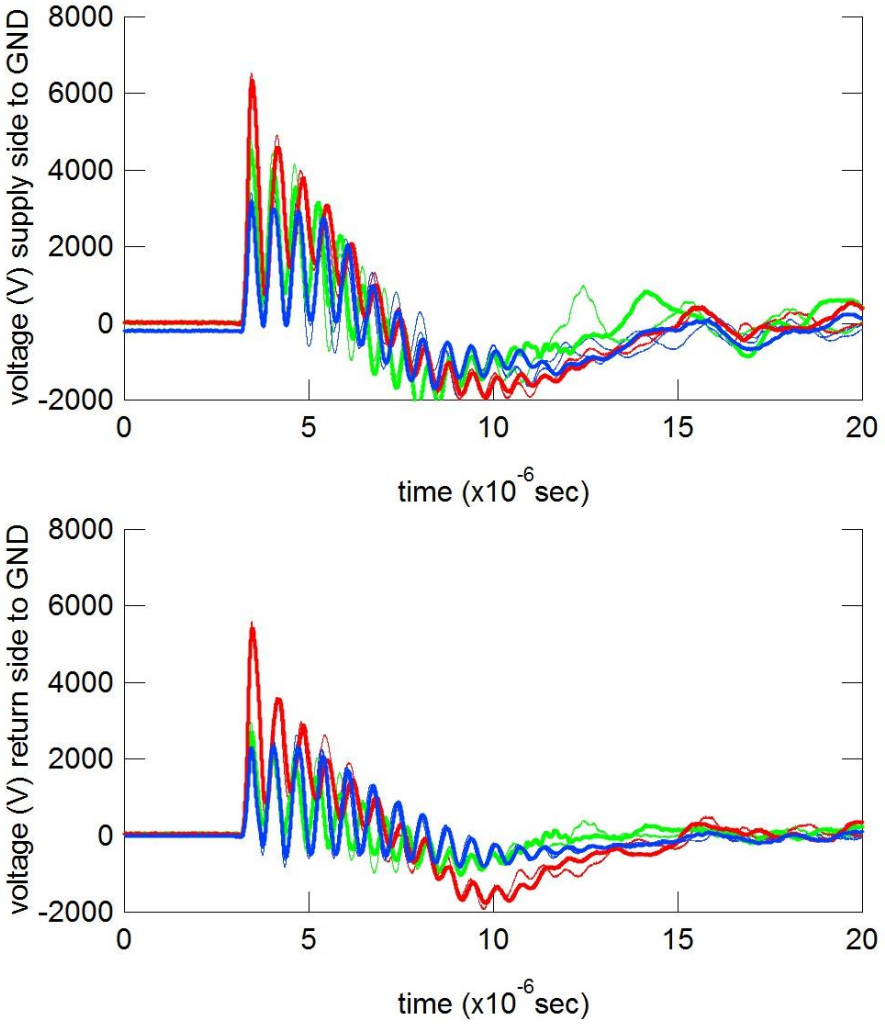

FC→
Additional inductance
From power supply
Capacitance box

Difference between additional L position





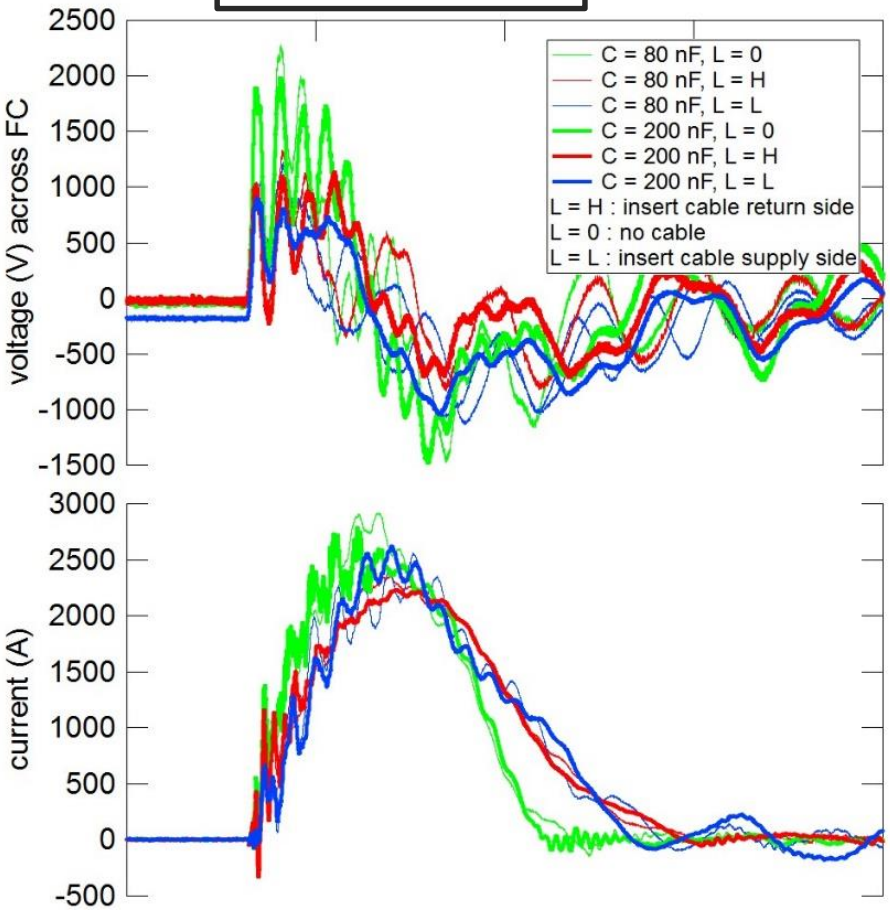
L=H : insert return side

L=0 : without additional L

L=L : insert supply side

Voltage and current

Es=5 kV (nominal 18 kV)



FC voltage	FC current	I/V (FC)
1148	2245	**1.96**
1992	2800	**1.41**
1064	2631	**2.47**
1757	2809	**1.60**
2561	2792	**1.09**

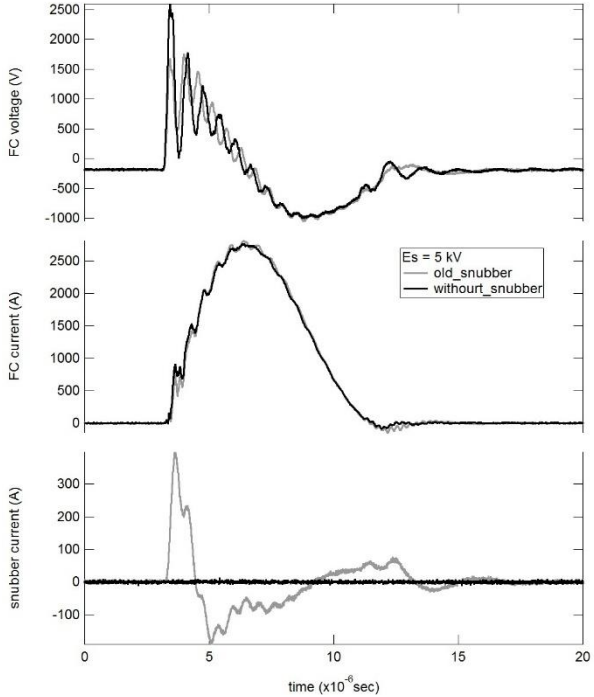
L=H : insert return side

L=0 : without additional L

L=L : insert supply side

Old circuit

Without both L and C



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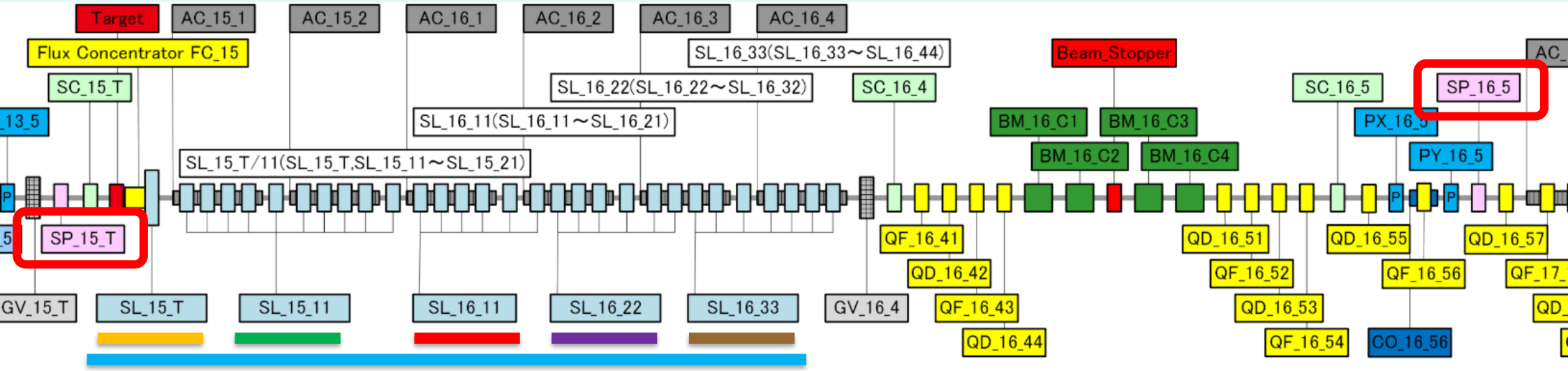
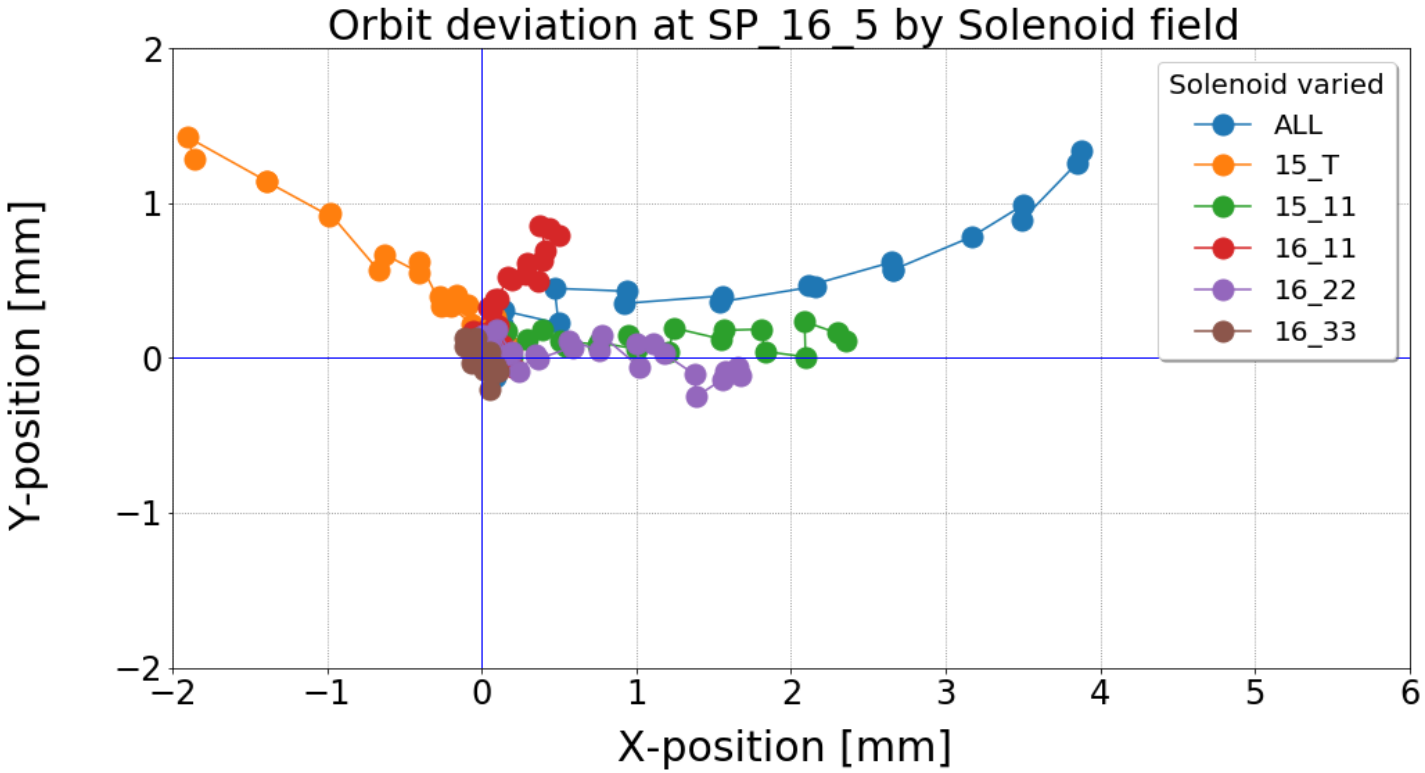
Orbit deflection in solenoid section



Measured by T. Kamitani



SP : BPM
SL : solenoid
QF/QD : quad
PX/PY : pusled steering

BM : bend
SC : screen
AC : acc. structure

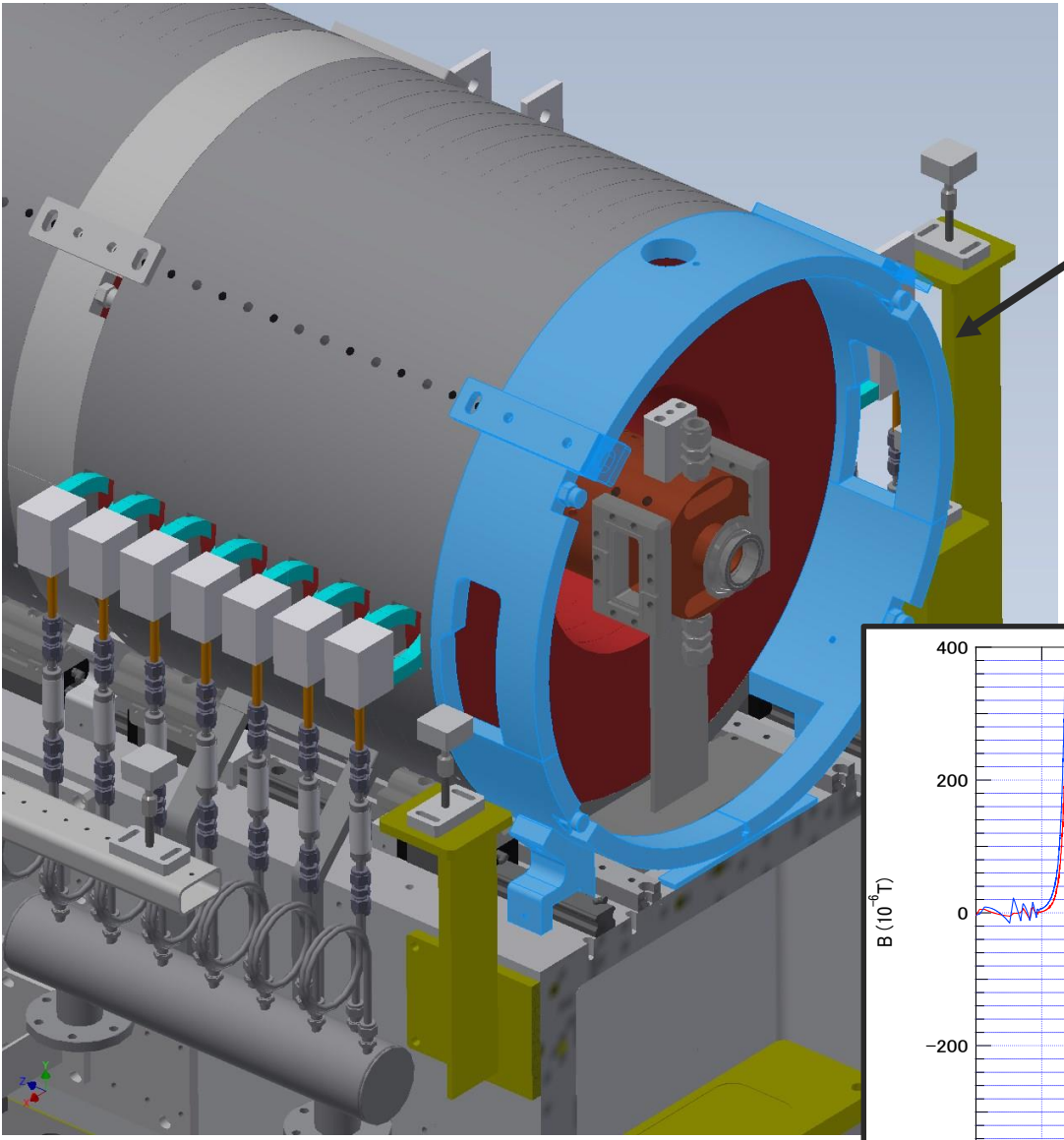
Measurement of deflection amount of 3 GeV electron beam by asymmetric field in solenoid section

1,Prepare ballistic beam between SP_15_T and SP_16_5

2,Energize a part of solenoid by 1/10* max. value step.

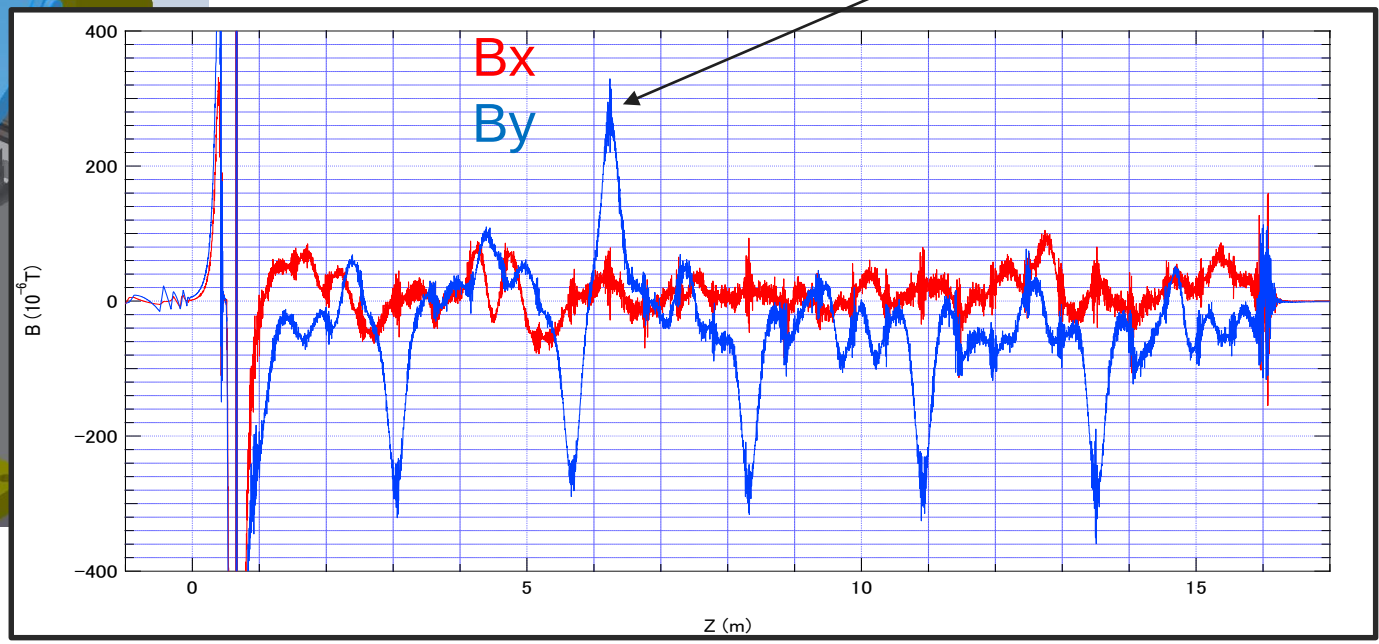
3, Monitor beam position at SP_16_5

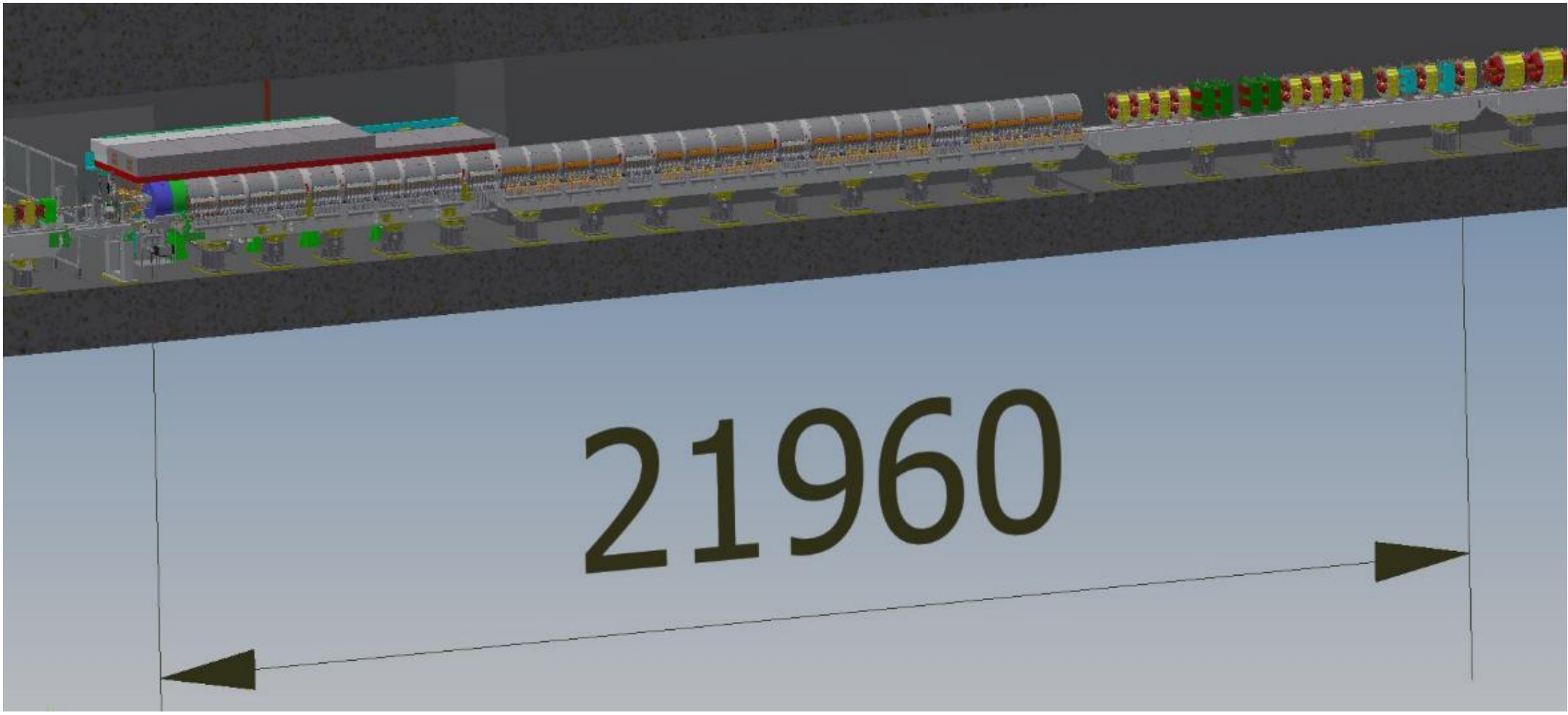
Asymmetry of magnetic connection



Iron yoke to connect flux of solenoid
need space for waveguide and support

Inner diameter of solenoid changes



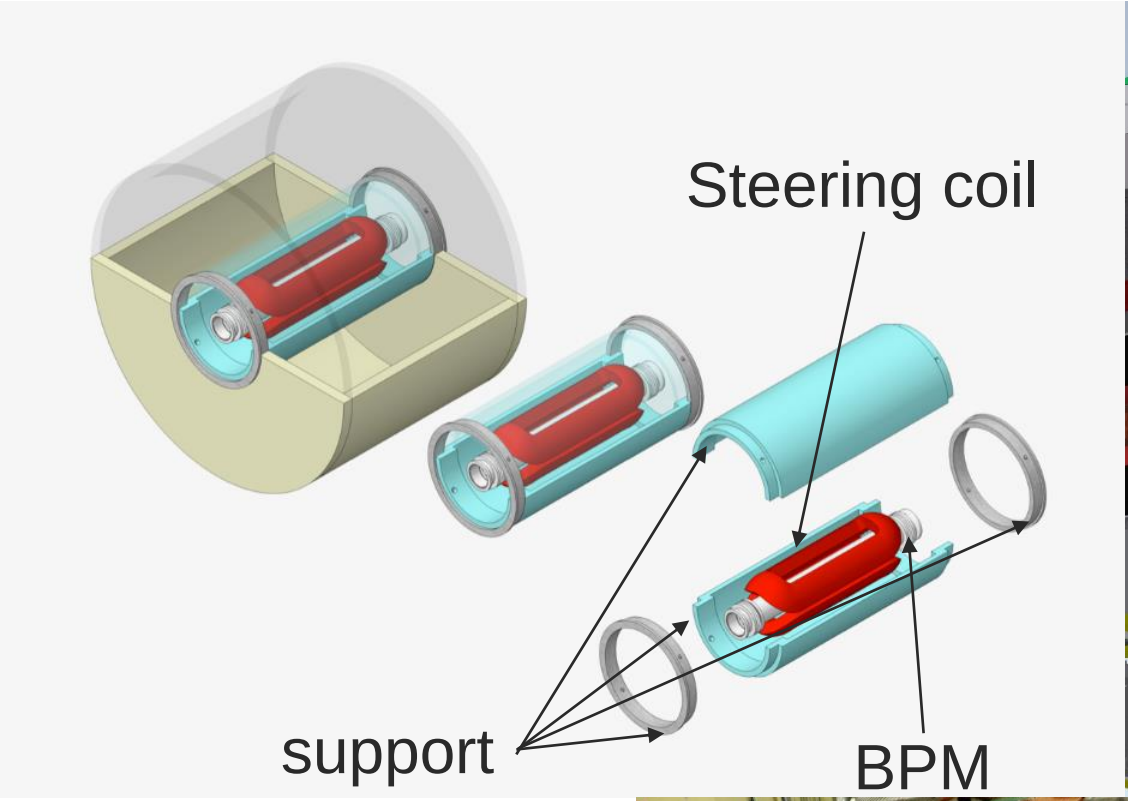


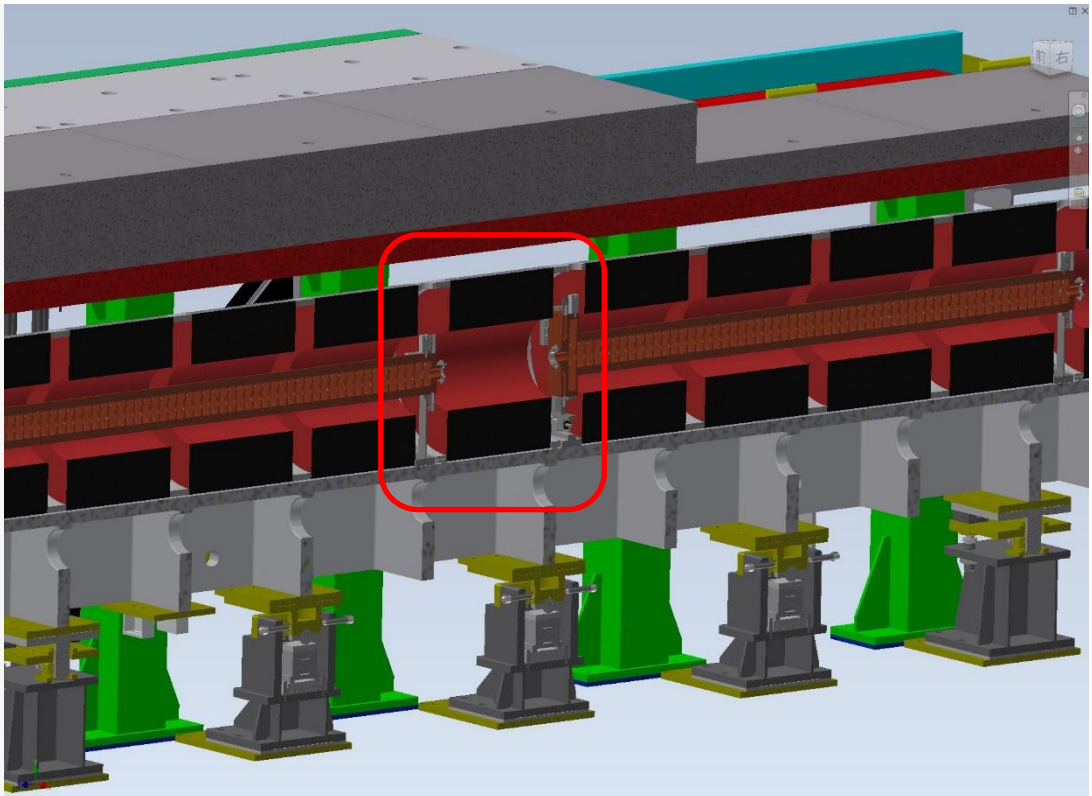
target

BPM and 1st steering

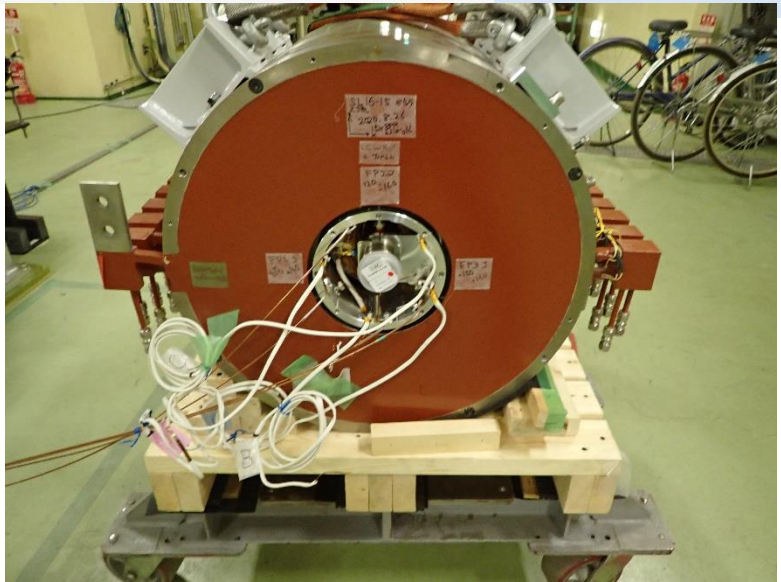
There were no BPMs and steerings for 22 m after the target

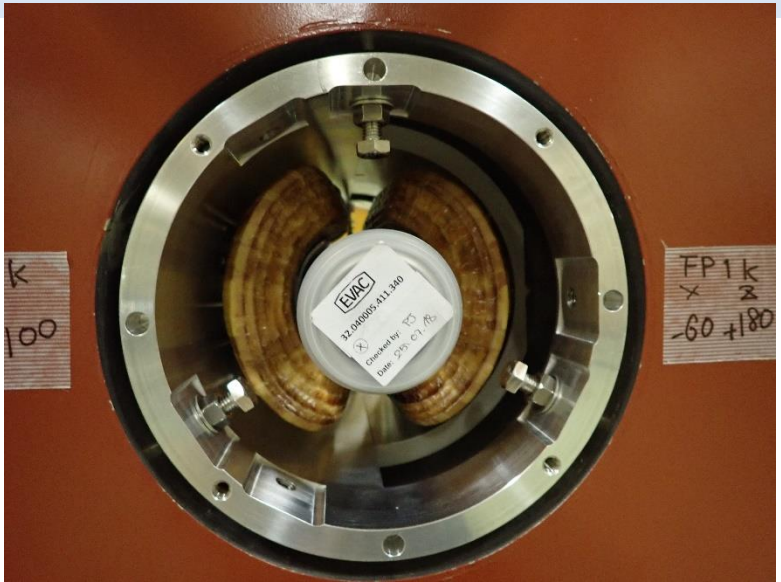
BPM and steering coils inside solenoid





K. Yokoyama and K. Kakihara



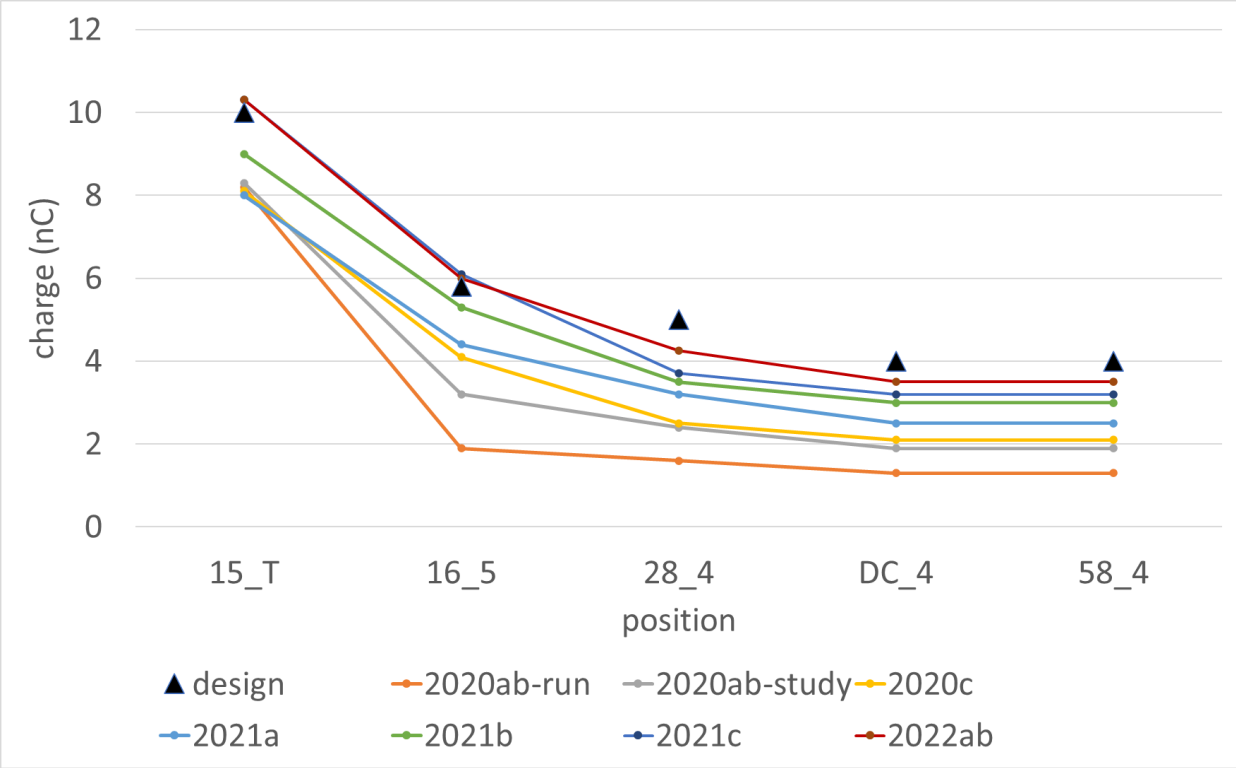


History of improvement

position	design	2020ab-run	2020ab-study	2020c	2021a	2021b	2021c	**2022ab**
15_T	10	8.2	8.3	8.1	8	9	10.3	**10.3**
16_5	5.8	1.9	3.2	4.1	4.4	5.3	6.1	**6**
28_4	5	1.6	2.4	2.5	3.2	3.5	3.7	**4.25**
DC_4	4	1.3	1.9	2.1	2.5	3	3.2	**3.5**
58_4	4	1.3	1.9	2.1	2.5	3	3.2	**3.5**

Major upgrade

15_T : primary beam just before target
16_5 : first BPM for positron
28_4 : just before dumping ring
DC_4 : just after dumping ring
58_4 : end of LINAC



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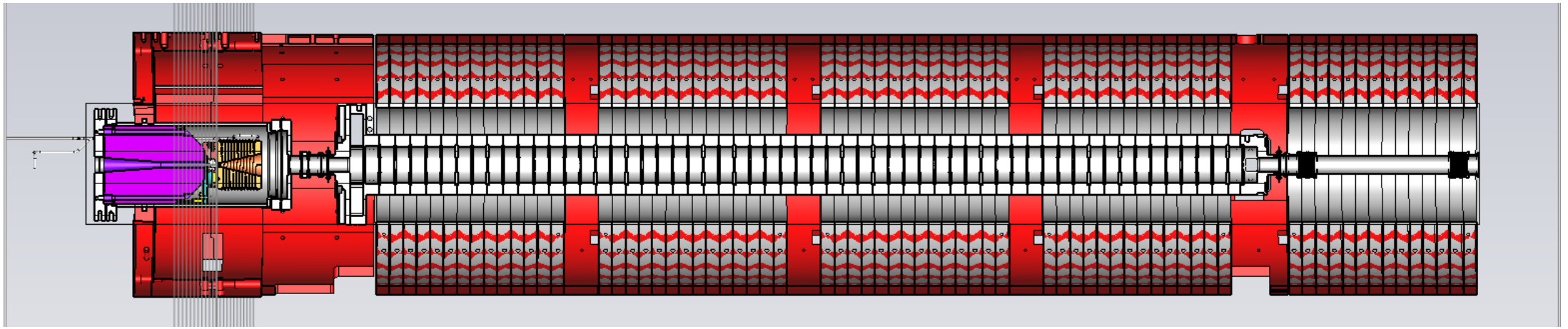
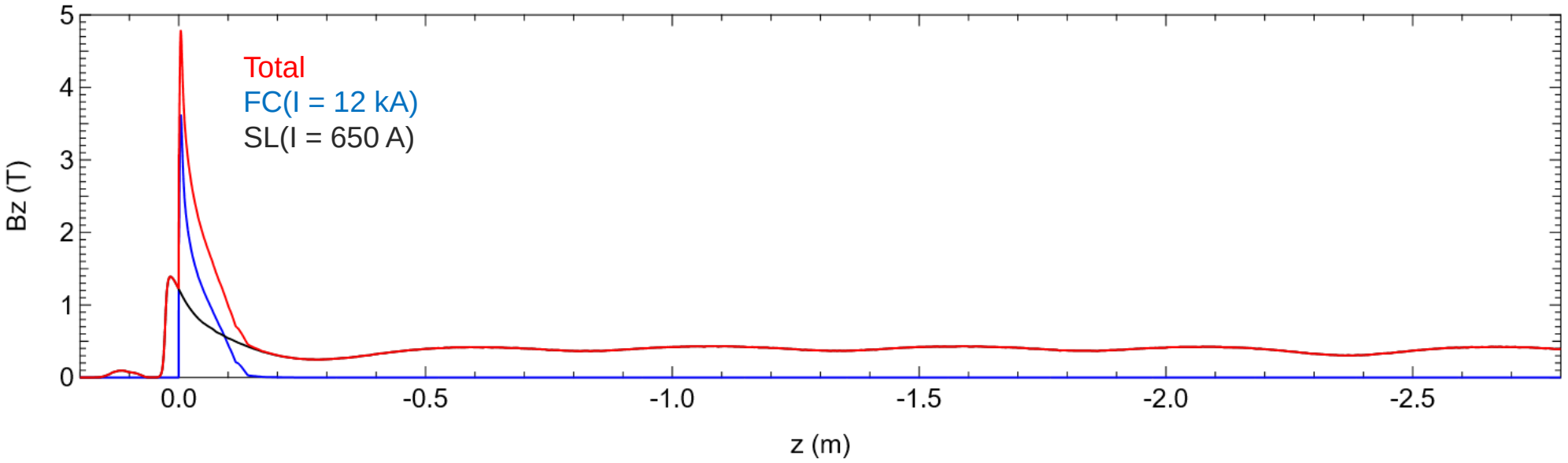
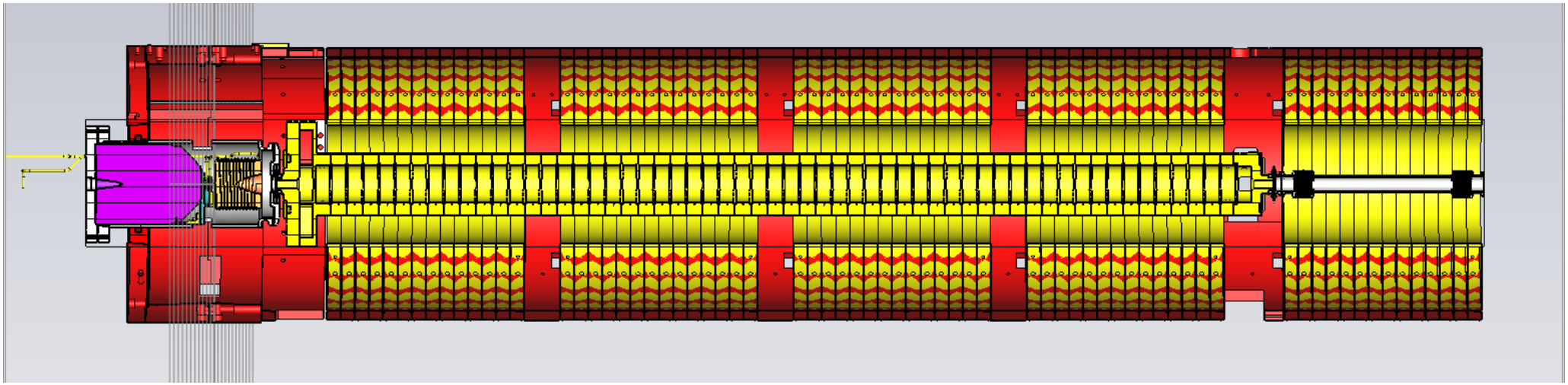
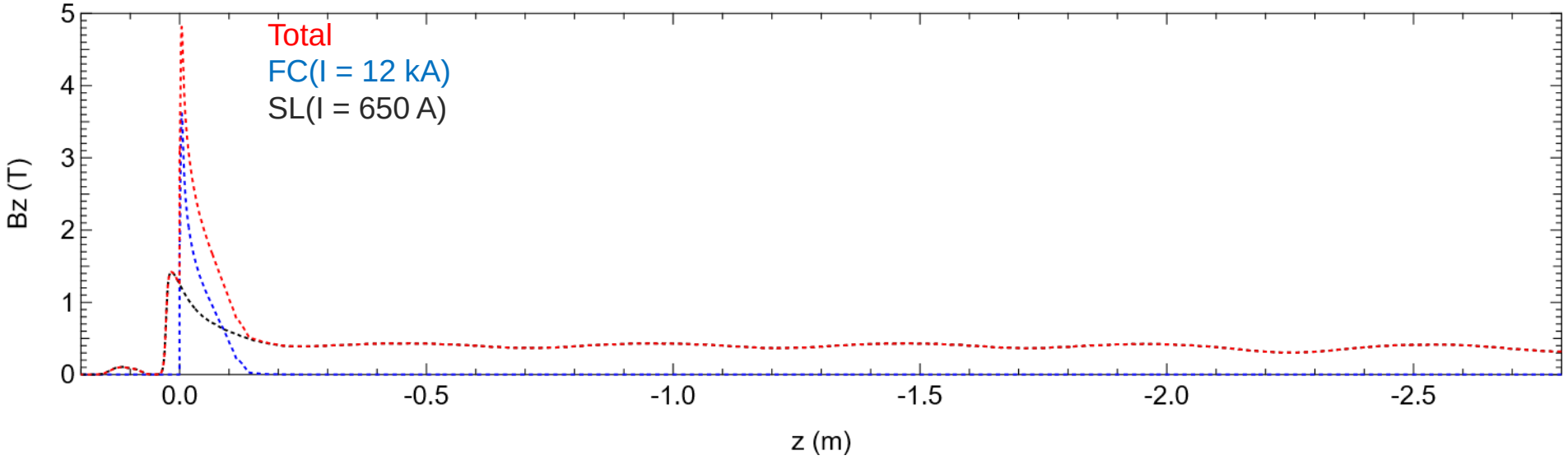
Present layout

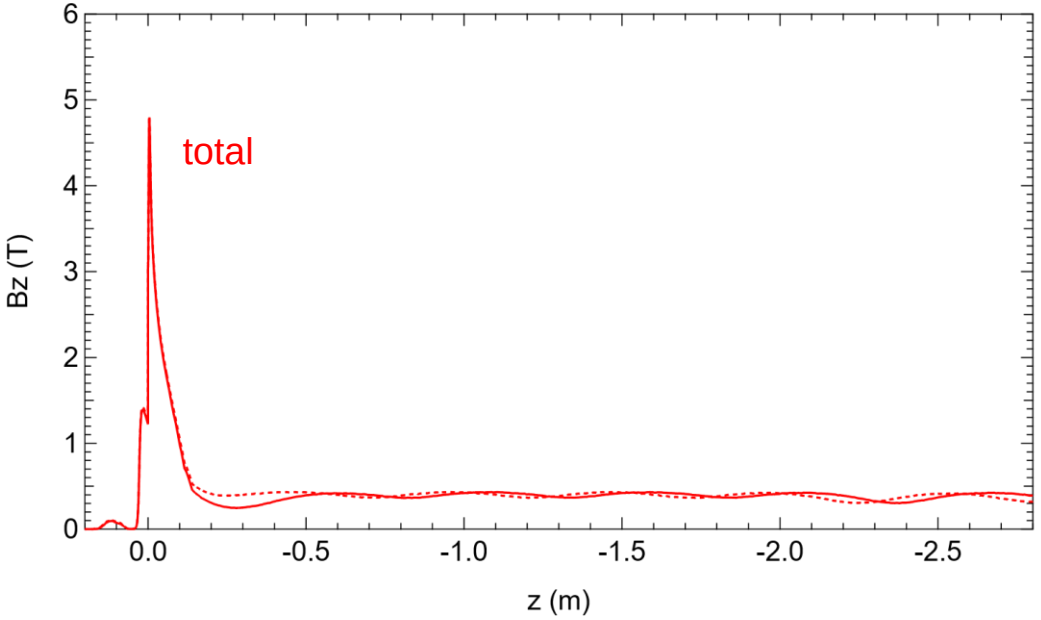


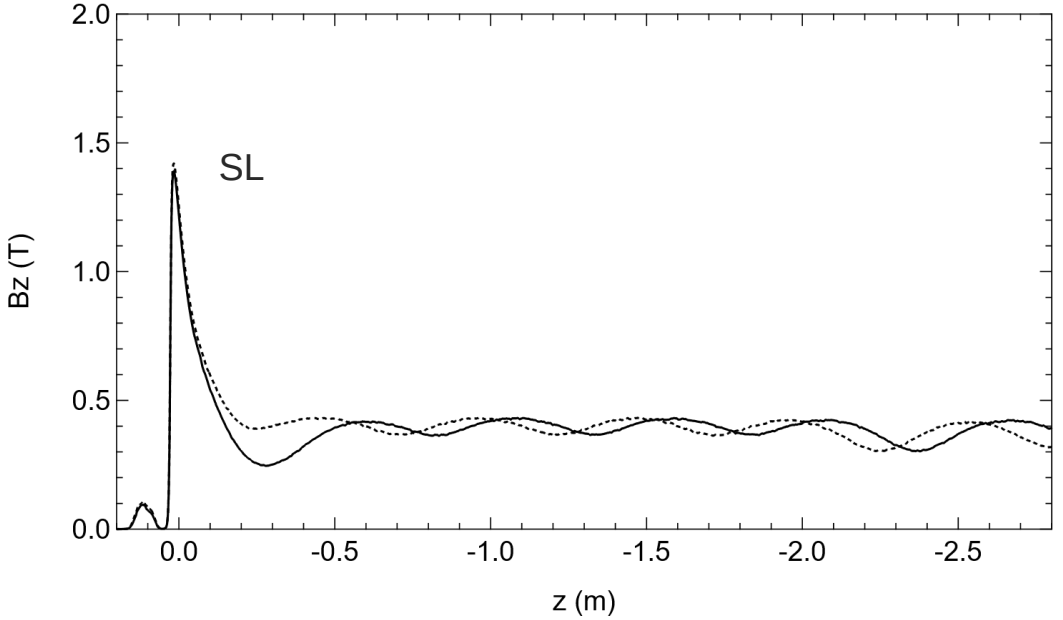


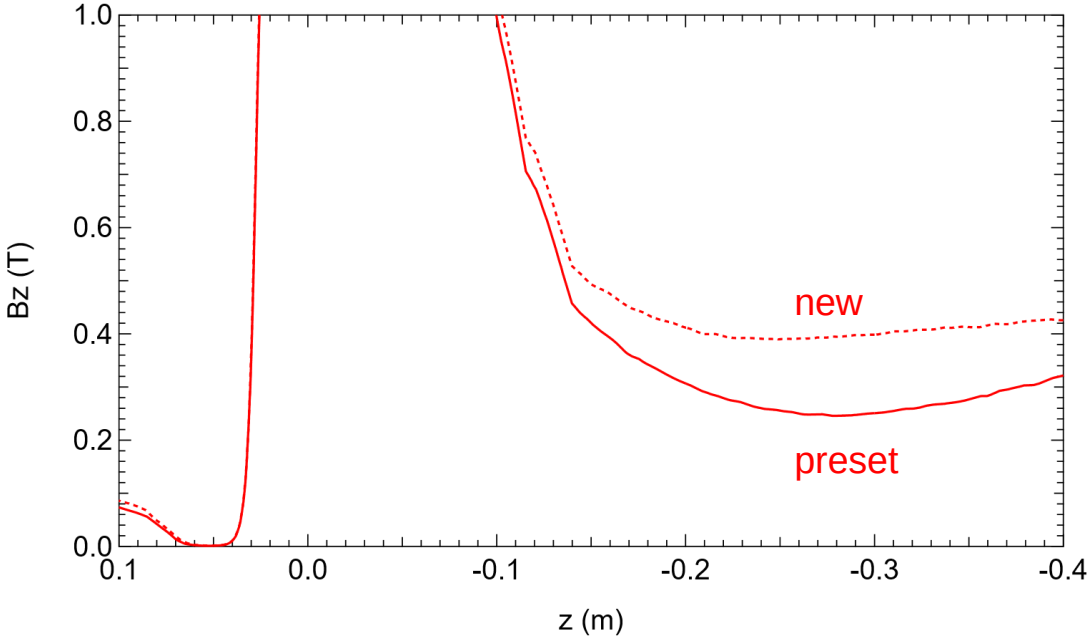
New layout

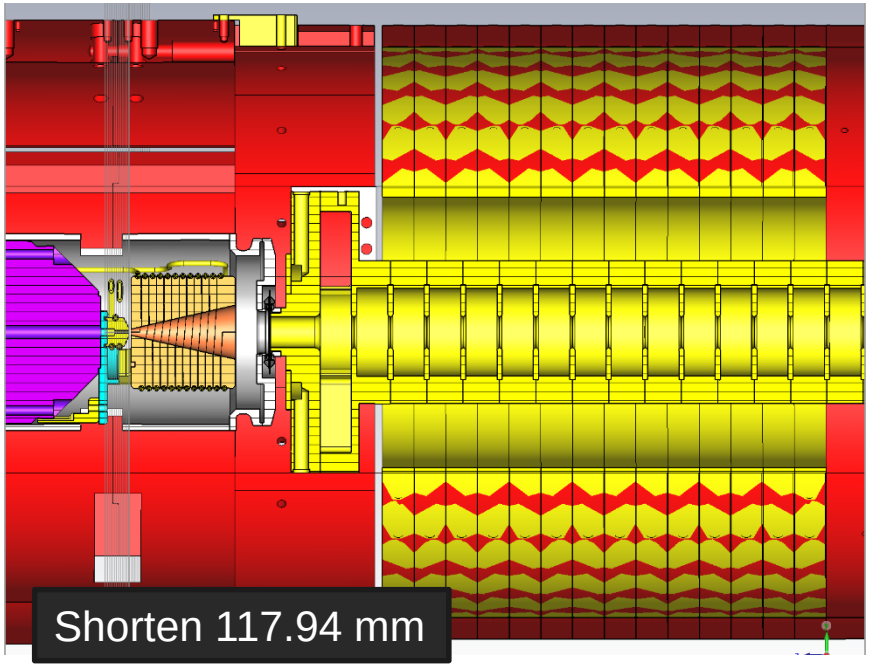


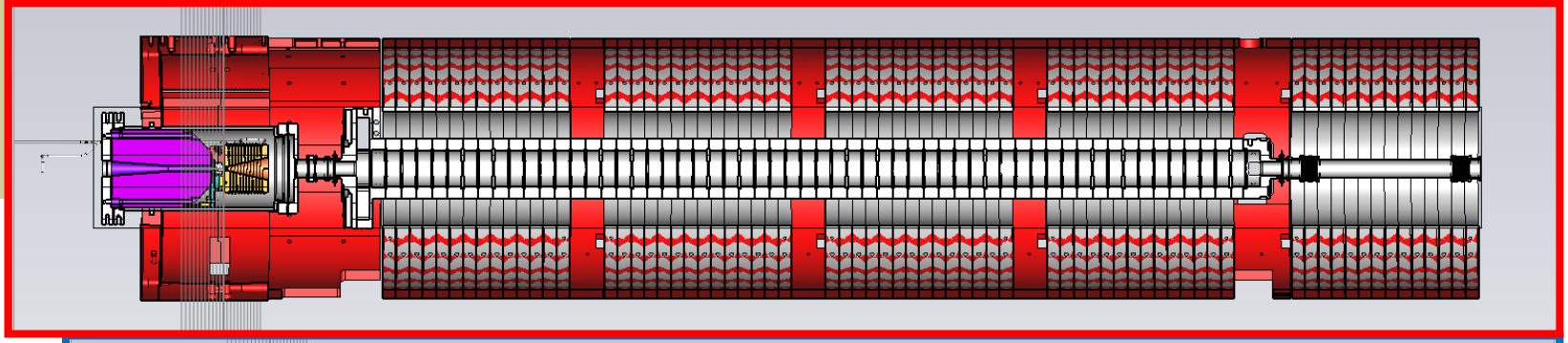


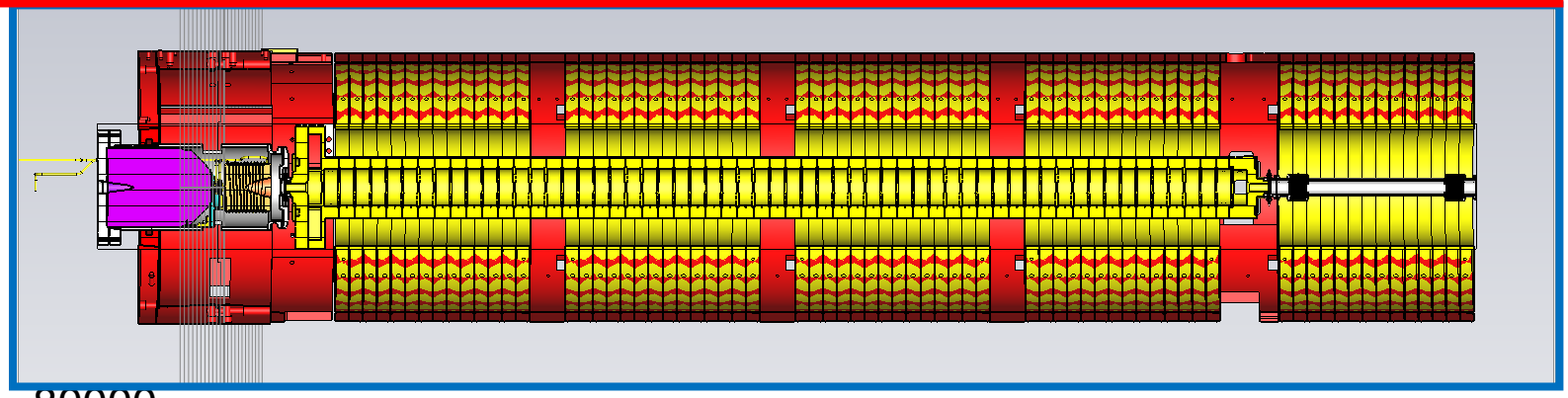

total
Bz (T)
z (m)
6
5
4
3
2
1
0
0.0
-0.5
-1.0
-1.5
-2.0
-2.5

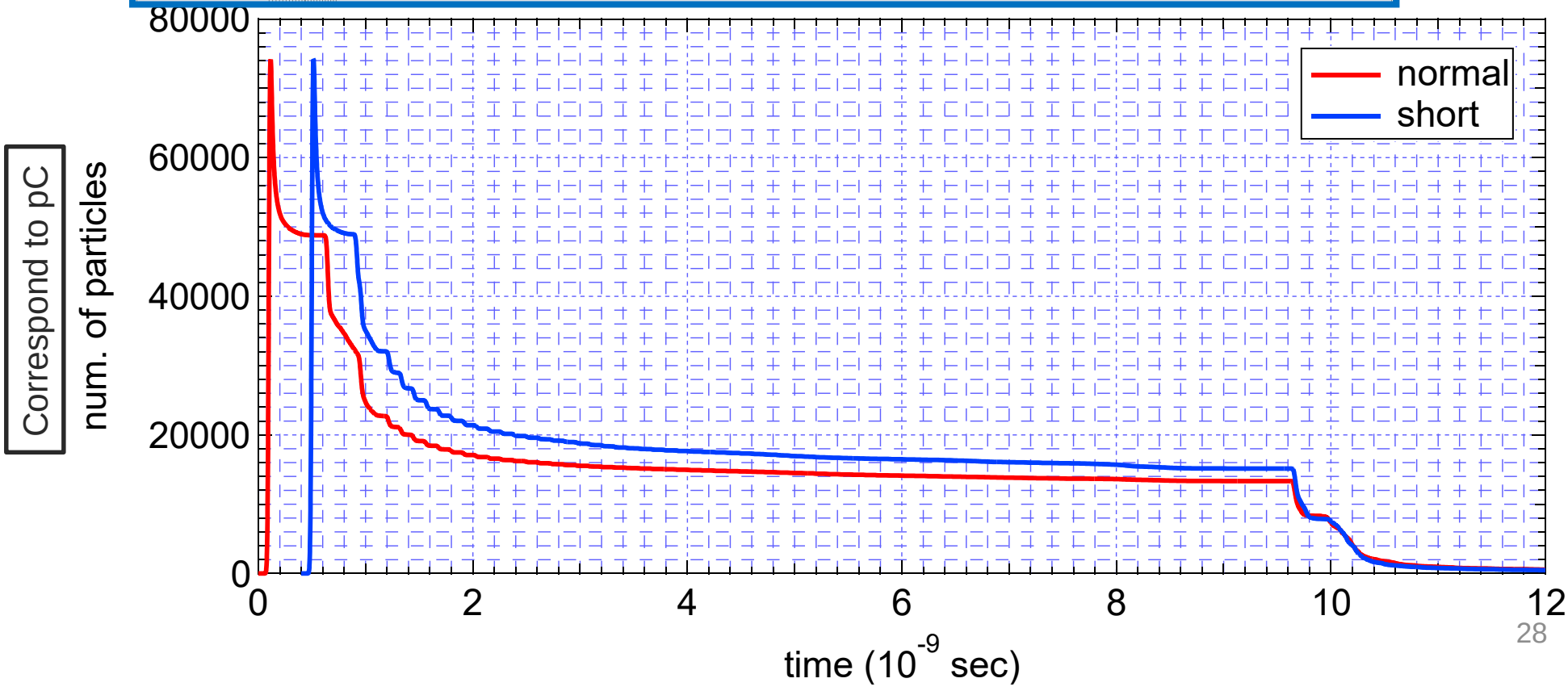

SL
Bz (T)
z (m)
2.0
1.5
1.0
0.5
0.0
0.0
-0.5
-1.0
-1.5
-2.0
-2.5

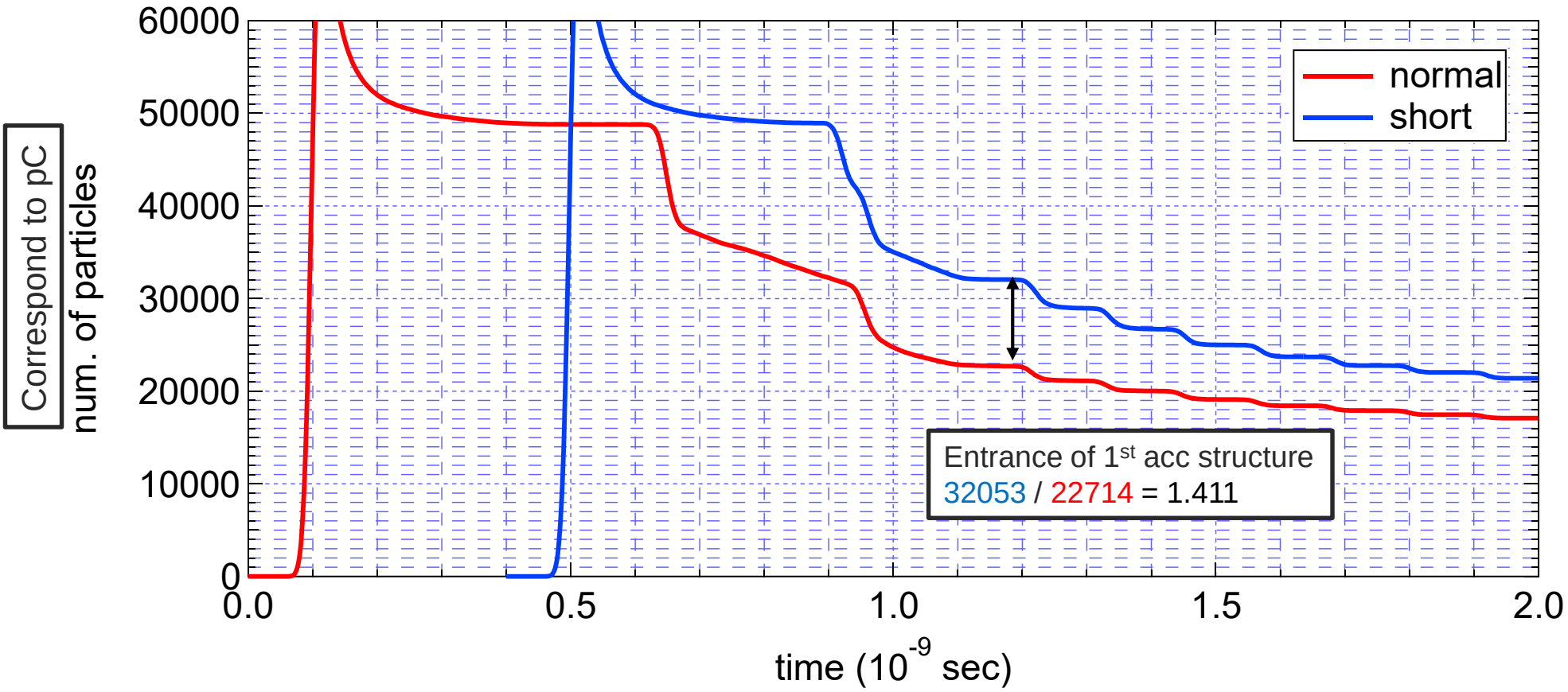

new
preset
Bz (T)
z (m)
1.0
0.8
0.6
0.4
0.2
0.0
0.1
0.0
-0.1
-0.2
-0.3
-0.4


Shorten 117.94 mm

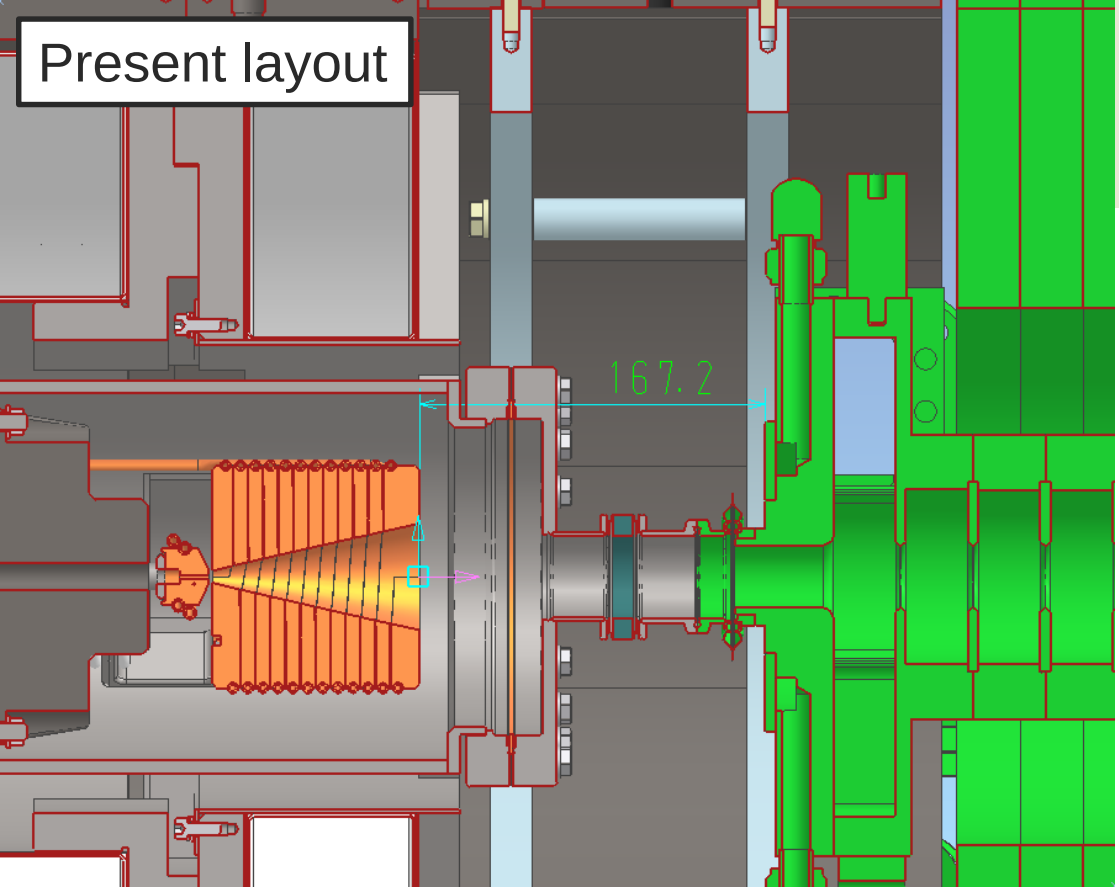





normal
short
Correspond to pC
num. of particles
time (10^-9 sec)
0
20000
40000
60000
80000
0
2
4
6
8
10
12


Correspond to pC
num. of particles
60000
50000
40000
30000
20000
10000
0
0.0
0.5
1.0
1.5
2.0
time (10^{-9} sec)
normal
short
Entrance of 1st acc structure
32053 / 22714 = 1.411

Present layout



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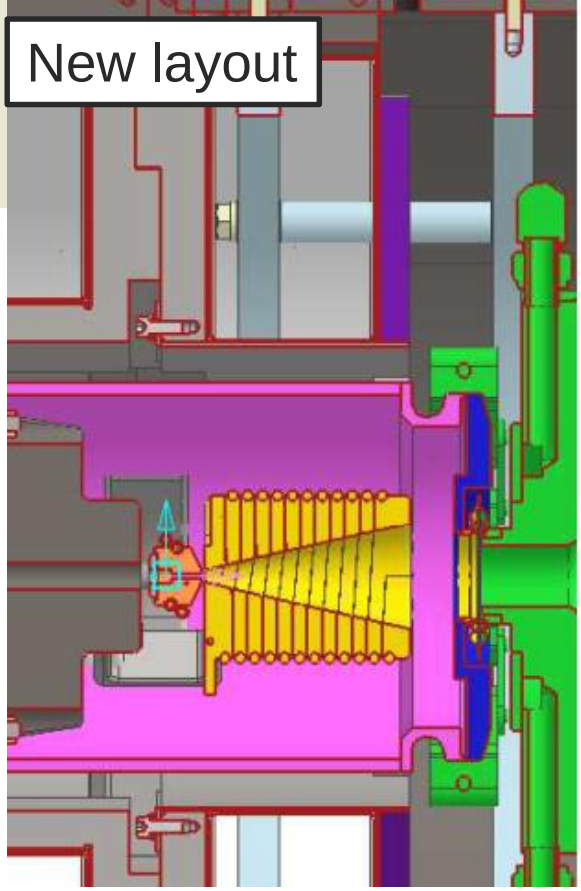
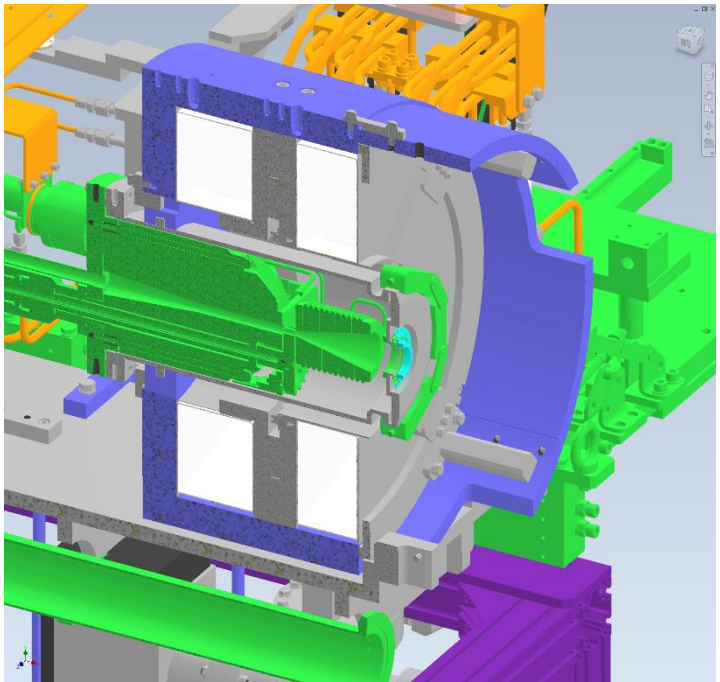
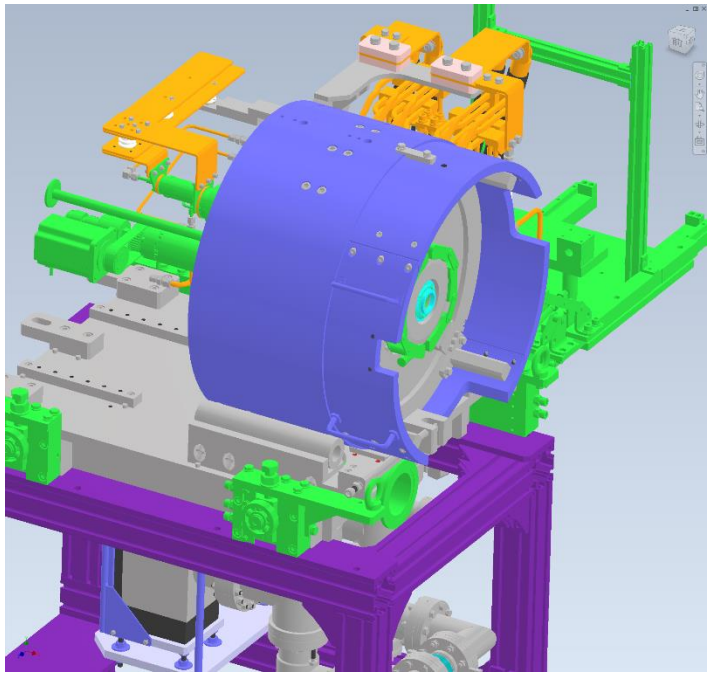


Detail design finished
Ready for manufacturing





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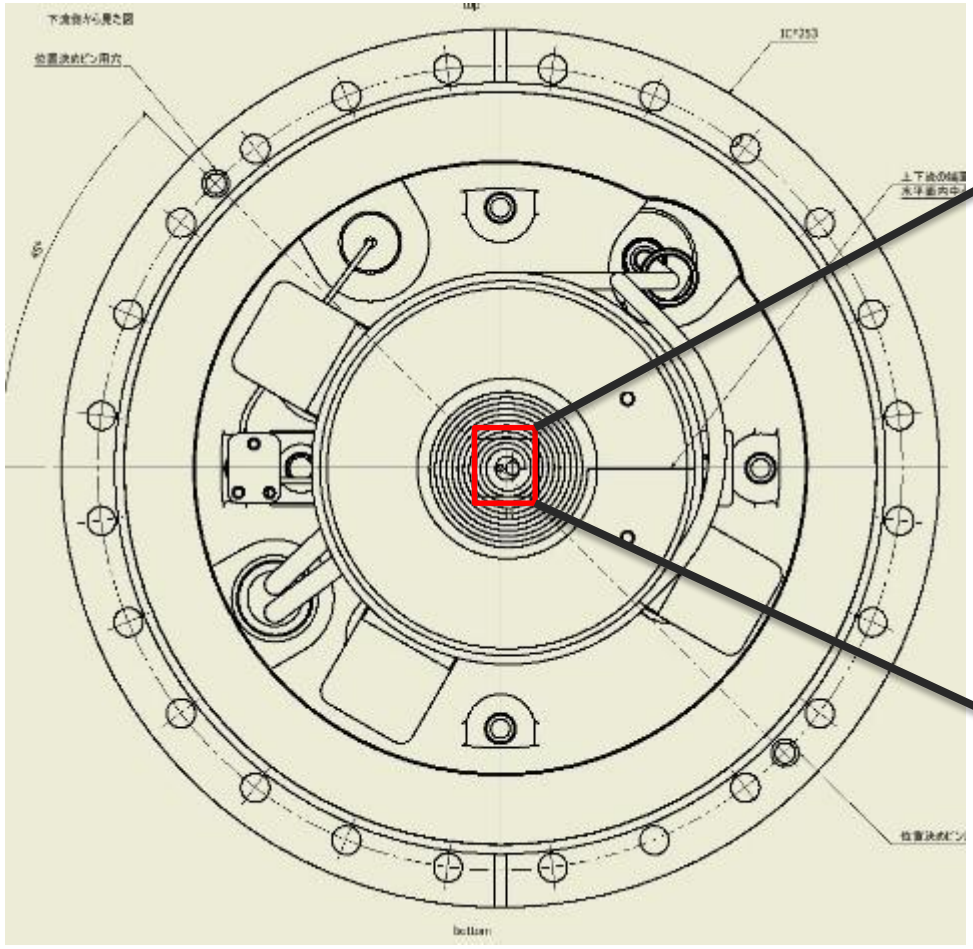
    - Change material of FC head
    - External circuit to reduce voltage
  - Improve beam handling
    - Install steering coils inside the solenoid
- Toward 4 nC and above
  - Shorten distance between FC and 1st acc. Structure
- Another topics
  - Rotating target
  - Full model simulation
  - Magnetic field measurement at test bench
  - Evaluation of W and W-Cu connection

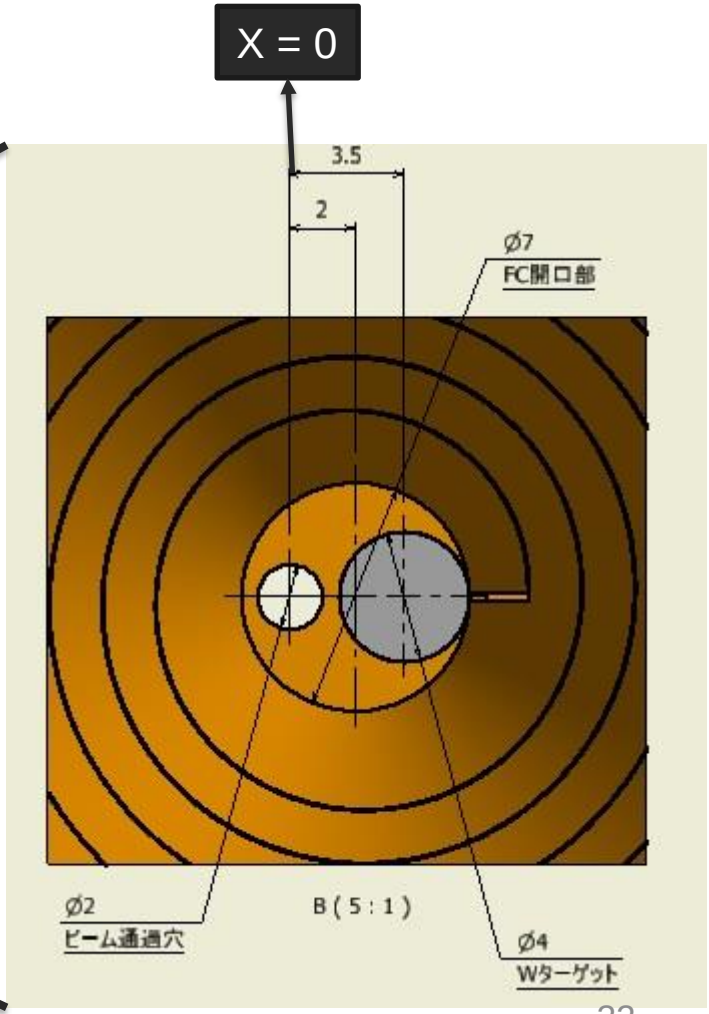
SuperKEKB positron source 3

Target material : W
Target size : Φ4 x 14
Inserted in the pule Cu block
Connected by HIP process

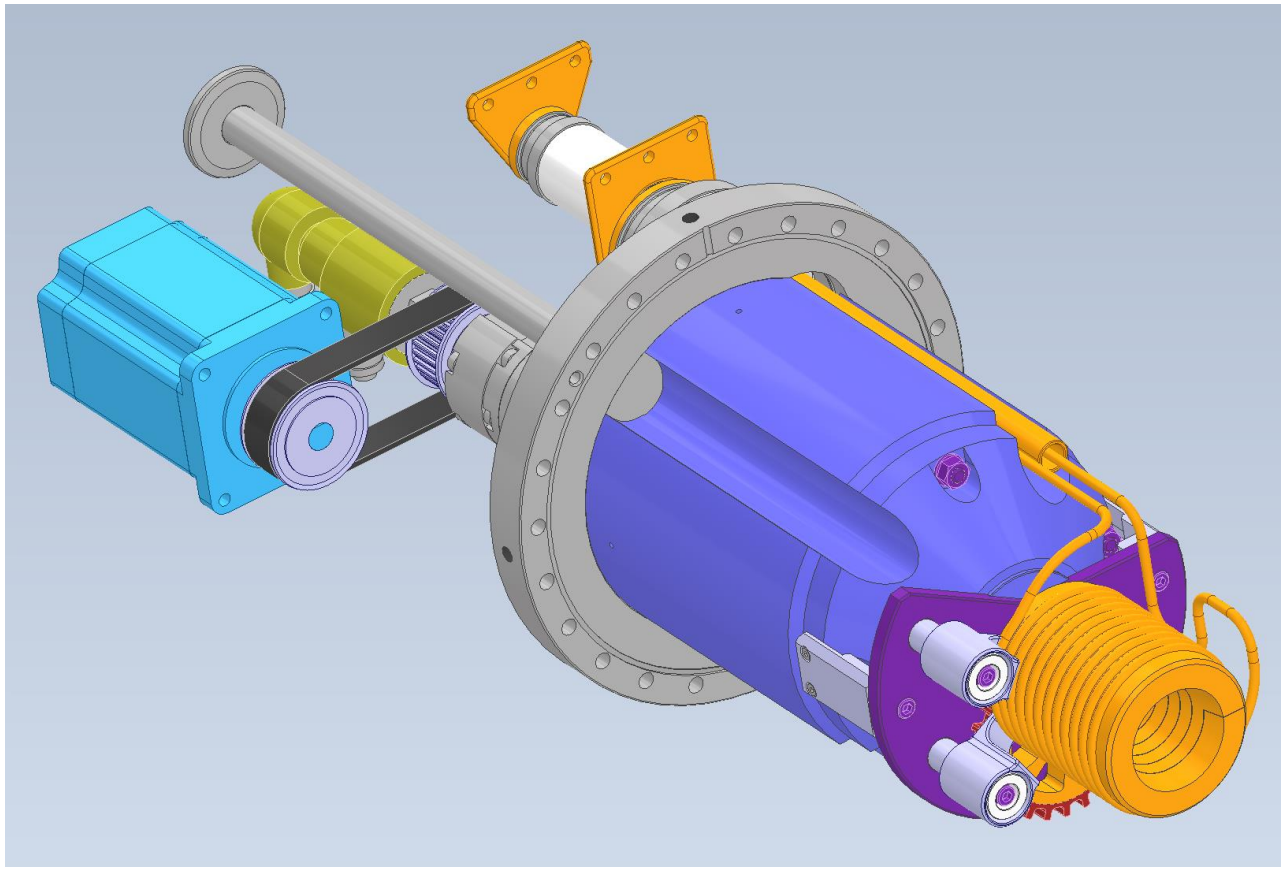
looking from downstream side

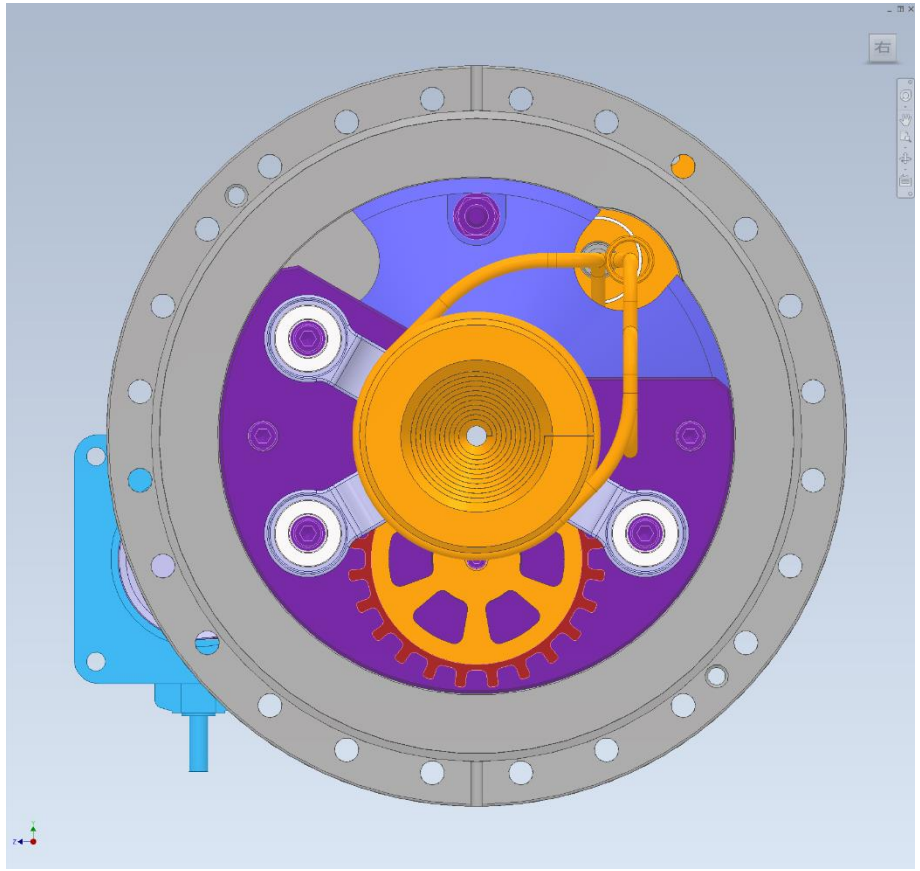
X = 0 hole for electron
X = 2 center of the FC
X = 3.5 center of the W target





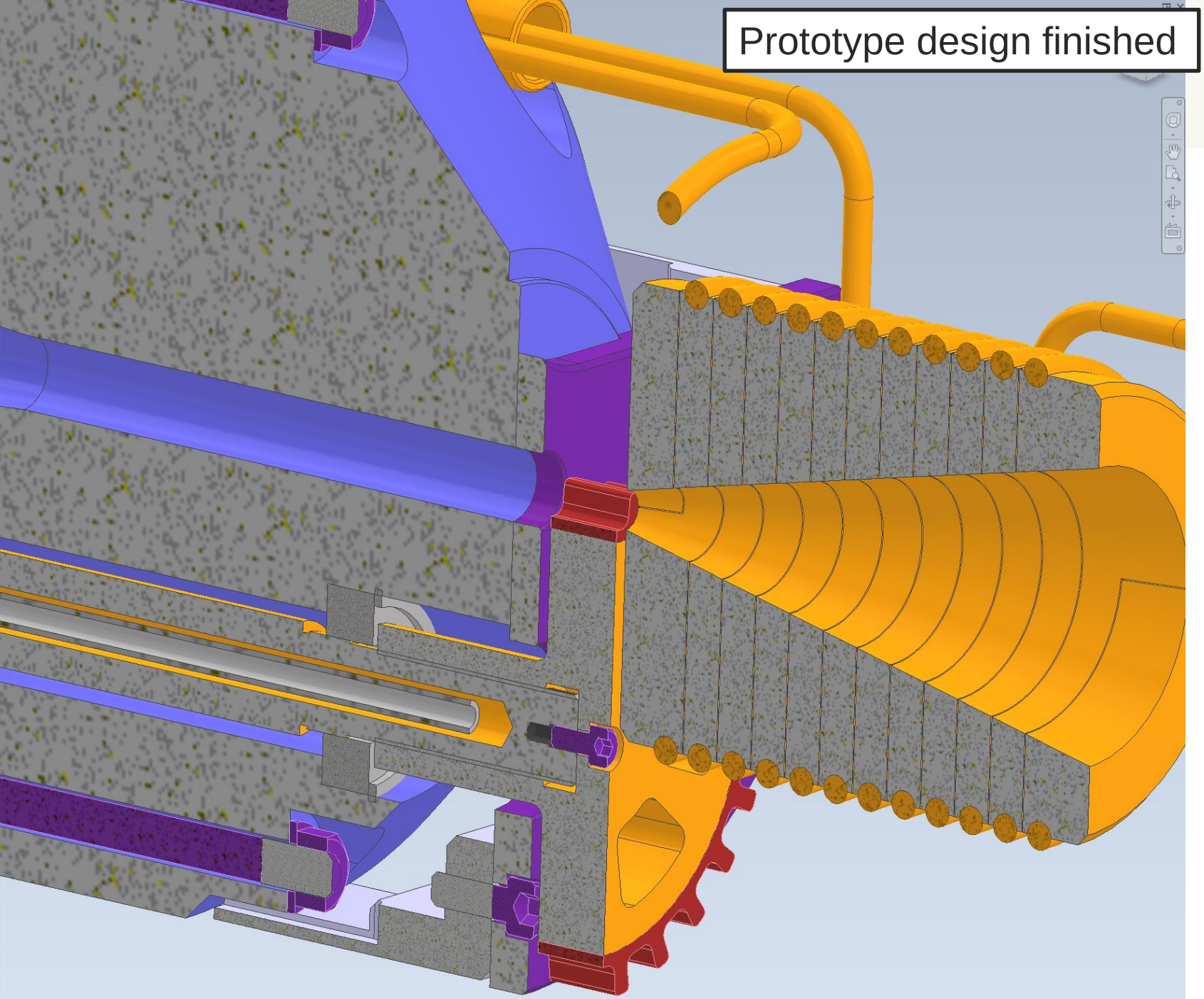
Rotating target for SuperKEKB positron source





Small hole limit tuning flexibility for electron beam
Switch free space and W target within 20 ms (50 Hz)

Prototype design finished

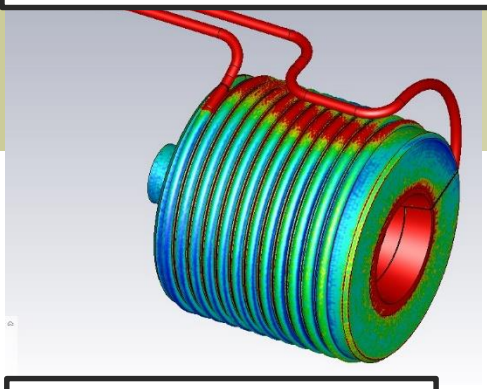


Gear-shape W target

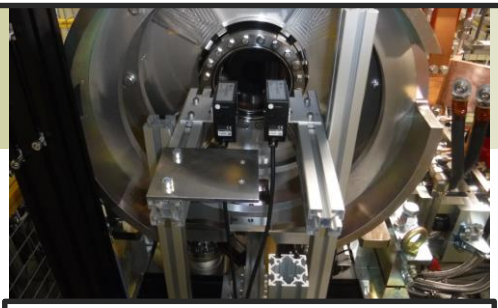
Topics

- From 1 nC to 3.5 nC
  - Solve discharge problem of FC
    - Change material of FC head
    - External circuit to reduce voltage
  - Improve beam handling
    - Install steering coils inside the solenoid
- Toward 4 nC and above
  - Shorten distance between FC and 1st acc. Structure
- Another topics
  - Rotating target
  - Full model simulation
  - Magnetic field measurement at test bench
  - Evaluation of W and W-Cu connection

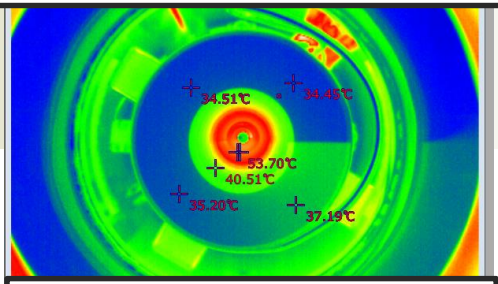
Cited from US-Japan proposal “An Integrated Simulation Tool for Dark Current Radiation Effects and Positron Sources in Particle Accelerators”



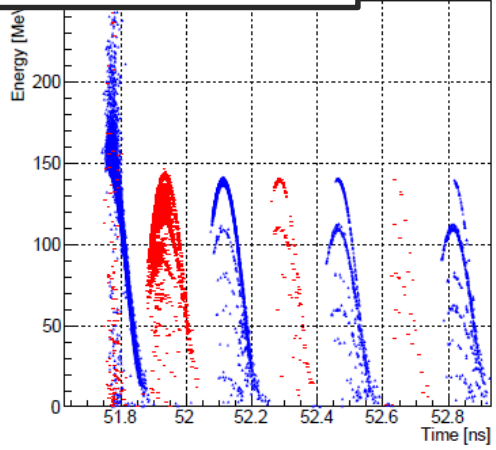
Time-dependent magnetic field and current distribution simulation



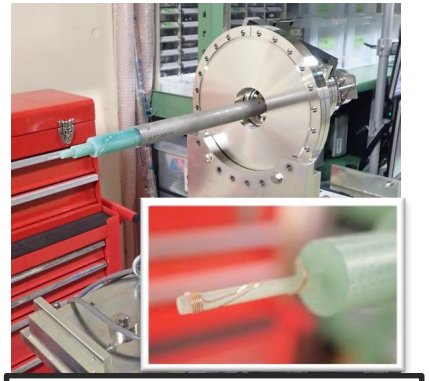
Vibration measurement by laser displacement monitor



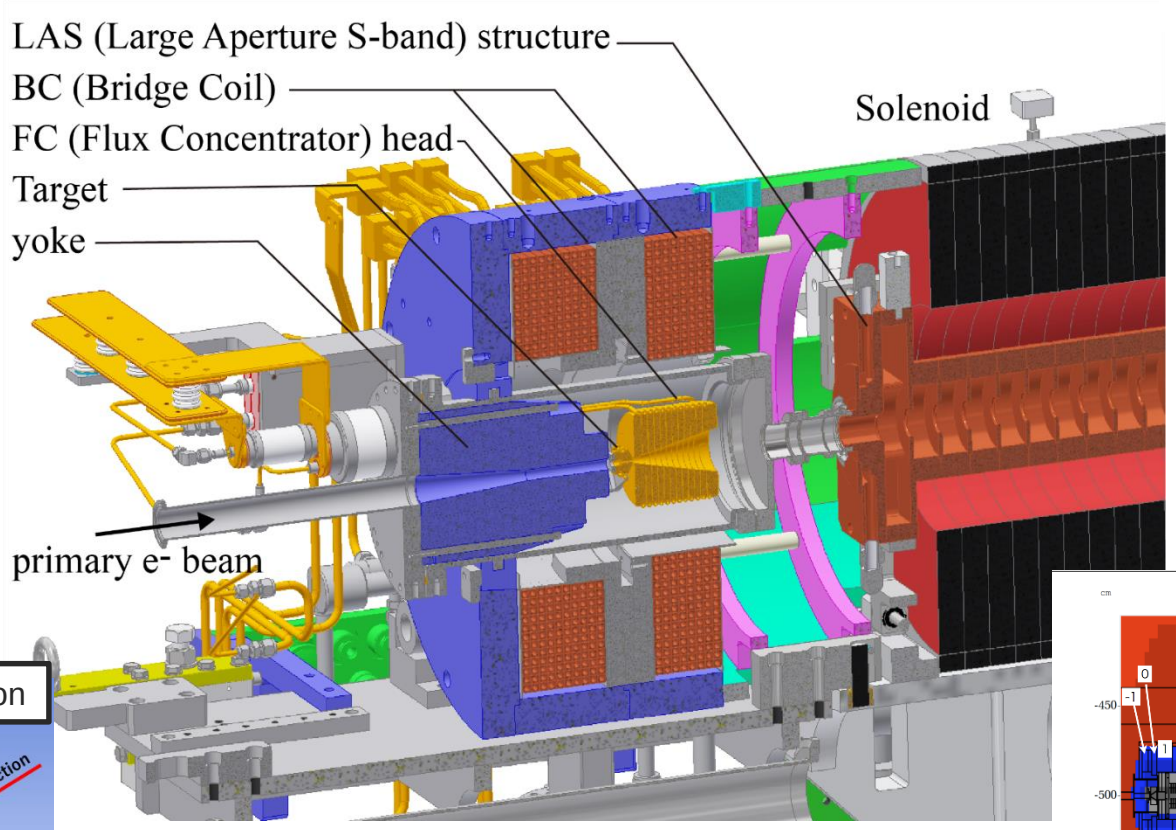
Temperature distribution of the FC measured by a infra-red camera

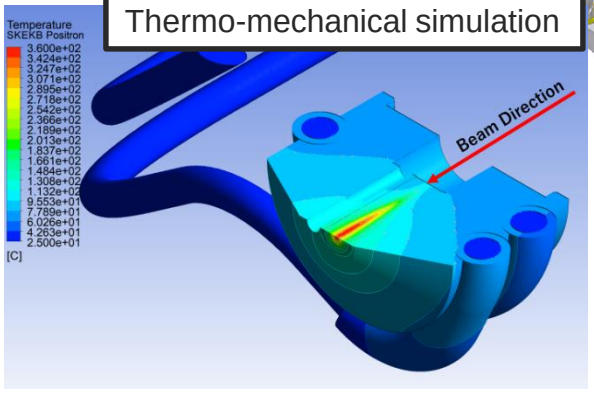


Particle tracking simulation



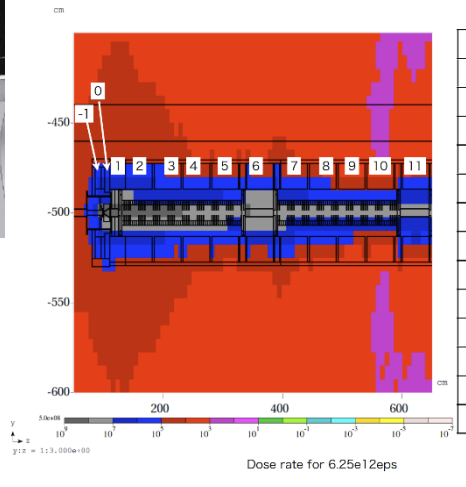
Field measurement using pick up coil on a motorized stage





Thermo-mechanical simulation

Radiation distribution simulation



Position	Dose[mSv/h]
-1	1.21E+06
0	1.78E+06
1	2.10E+06
2	2.40E+06
3	9.50E+05
4	4.20E+05
5	3.20E+05
6	6.10E+05
7	7.20E+05
8	2.40E+05
9	7.90E+04
10	2.80E+04
11	1.20E+05

Cited from US-Japan proposal “An Integrated Simulation Tool for Dark Current Radiation Effects and Positron Sources in Particle Accelerators”

Positron source as a benchmark for the simulation software

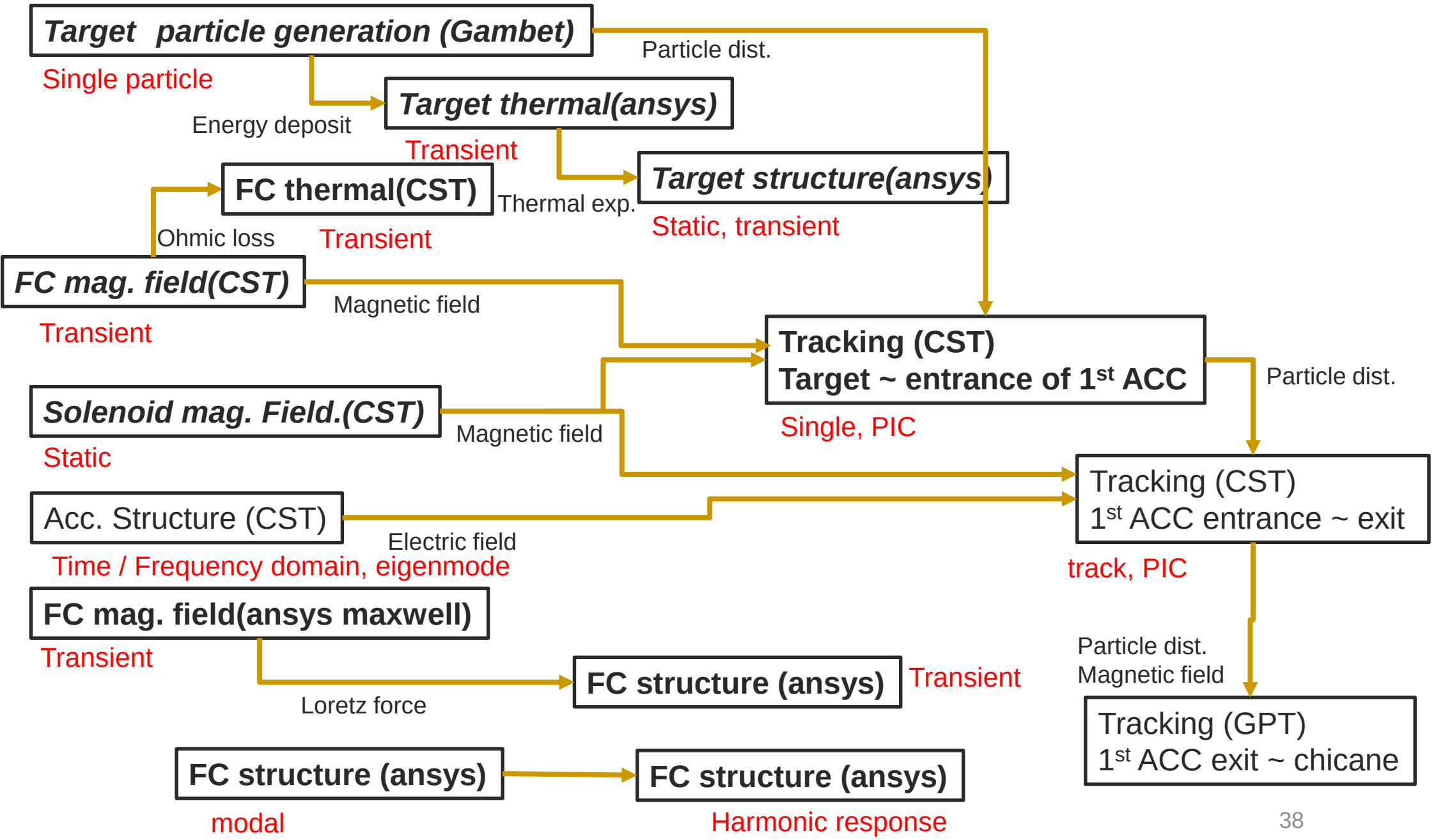
- Positron source is a microcosm of the accelerator
  - Highly multi-physical simulation is desired from radiation protection to particle tracking.
- Experimental test is hard
  - Need high power accelerator and heavy radiation shield.
  - Only a few sources are in operation in the world.
  - KEK has long operation experiences, test facility and the real positron source in operation.
- Input to the future project is important task
  - High intensity Positron source is one of the key device for future lepton colliders such as ILC, CLIC and FCC.
  - Careful and extensive simulation are crucial and ongoing.
  - Validation of the simulation method (i.e. comparison with experimental data) is important.

Object	Simulation software used till now
Solenoid field	CST (static B)
Pulsed magnet (FC)	CST (time dependent B) Ansys EM (electromagnetic and mechanical)
Target	Fluka, Eggs (radiation) Ansys (thermal, mechanical)
Radiation protection	Phits, Fluka
Acc. Structure	CST (RF), Superfish
Particle tracking (short range)	GPT, Geant4
Particle tracking (long range)	SAD, Elegant
Modeling	Inventor → STEP
Power supply and circuit	Ltspice, microcap

It is always troublesome to manage simulation conditions and parameters!!

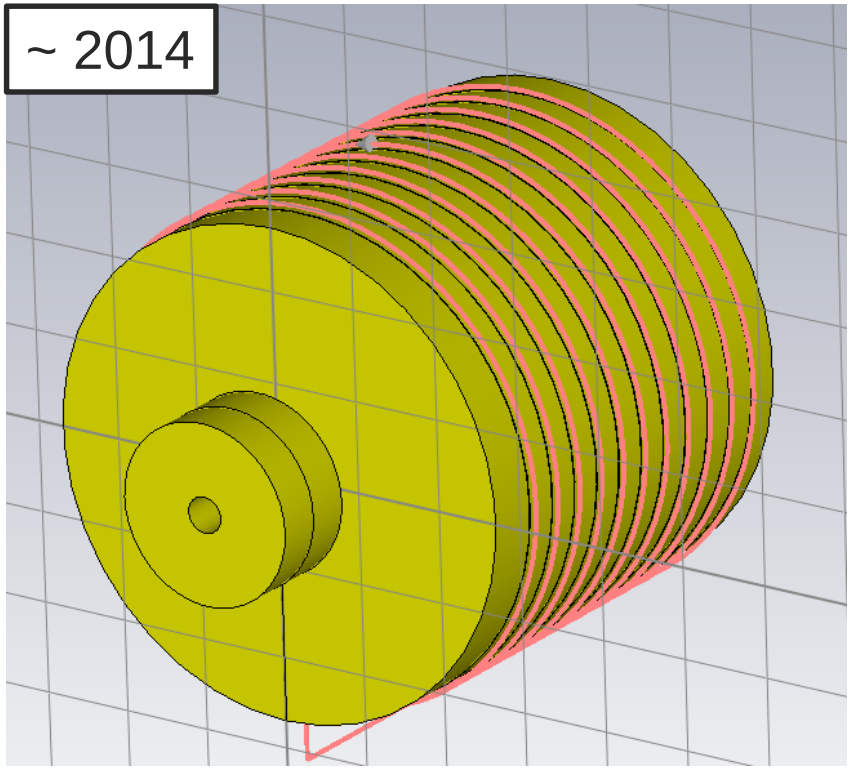
Comprehensive simulation software package has been desired for a long time.
We have many simulation results, experimental data, detailed CAD model and real machine.

Simulation flow of positron source

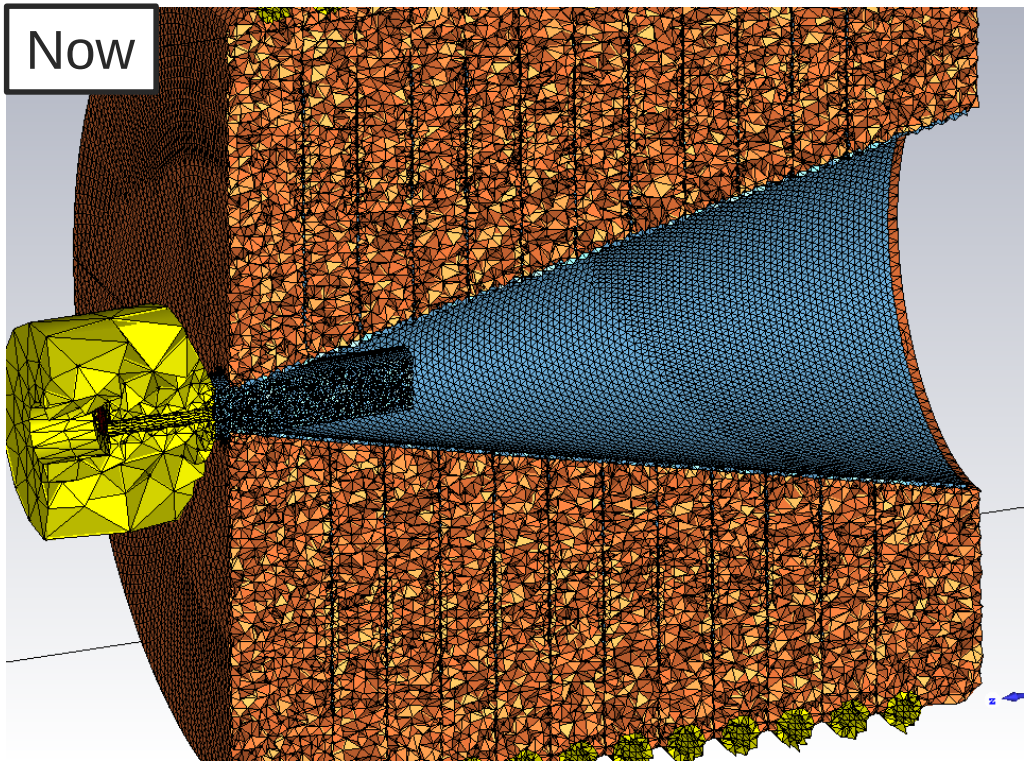


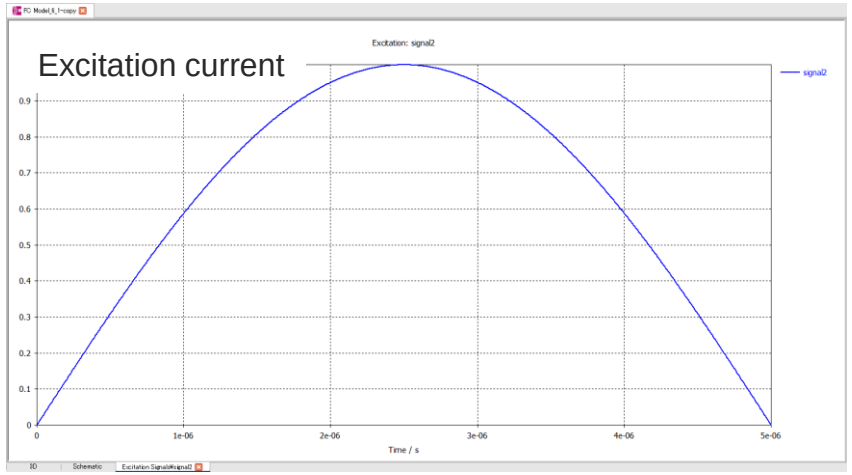
Transient Magnetic field simulation for FC

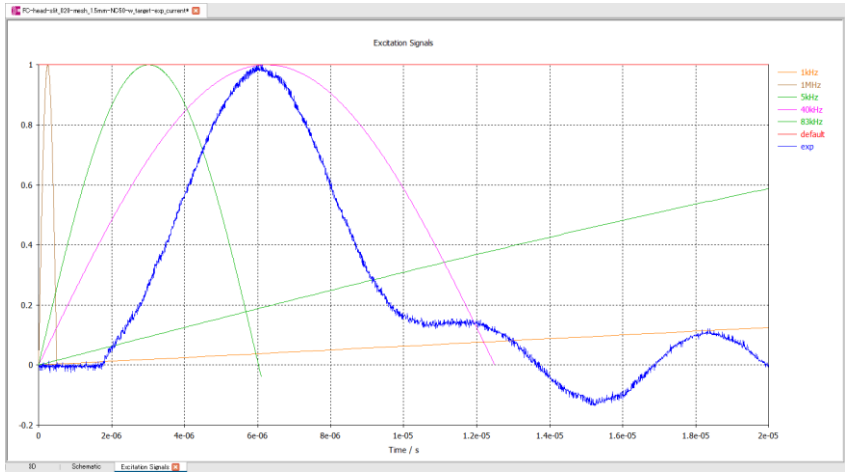
~ 2014



Now

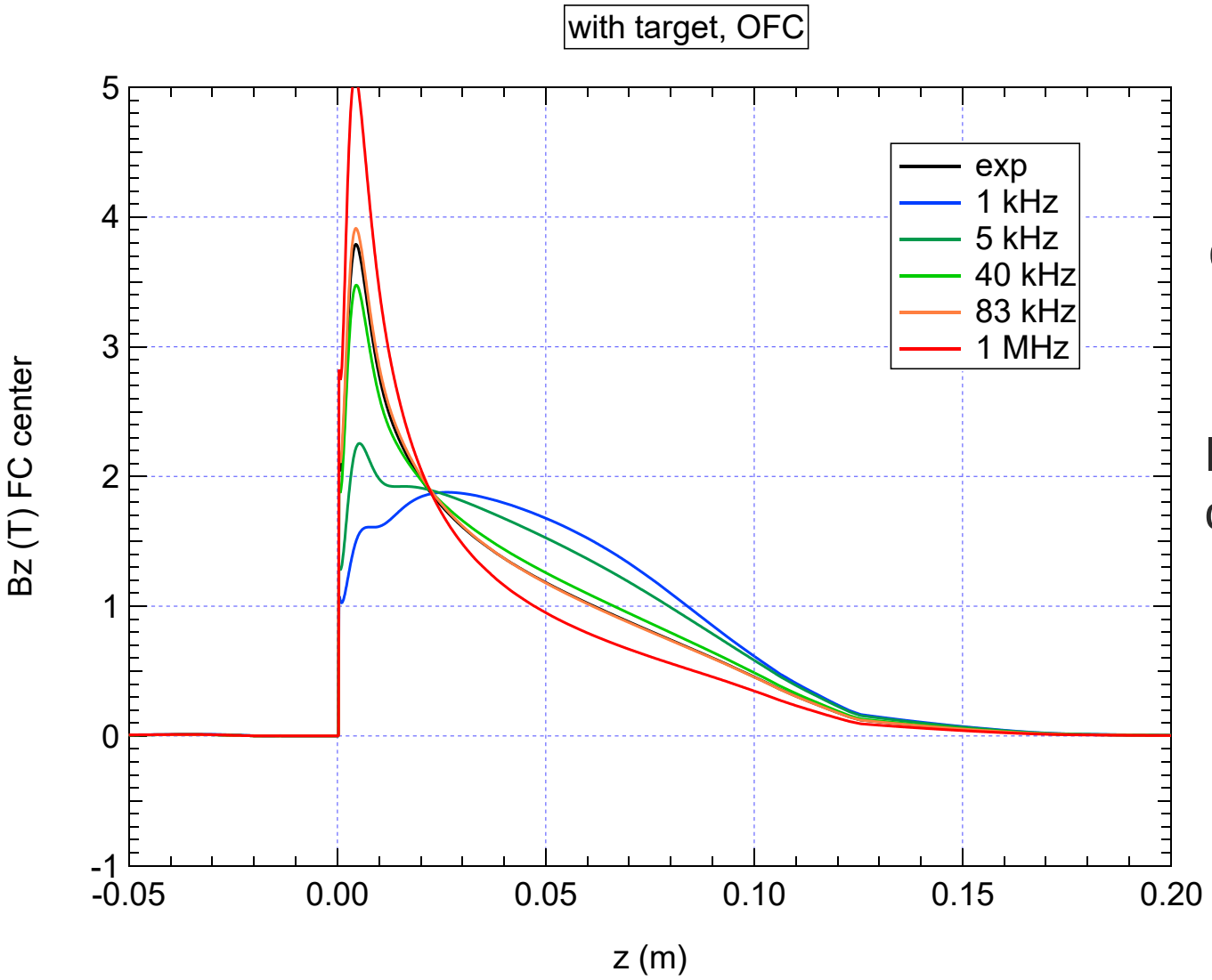






Simulation using realistic model and measured current shape was established

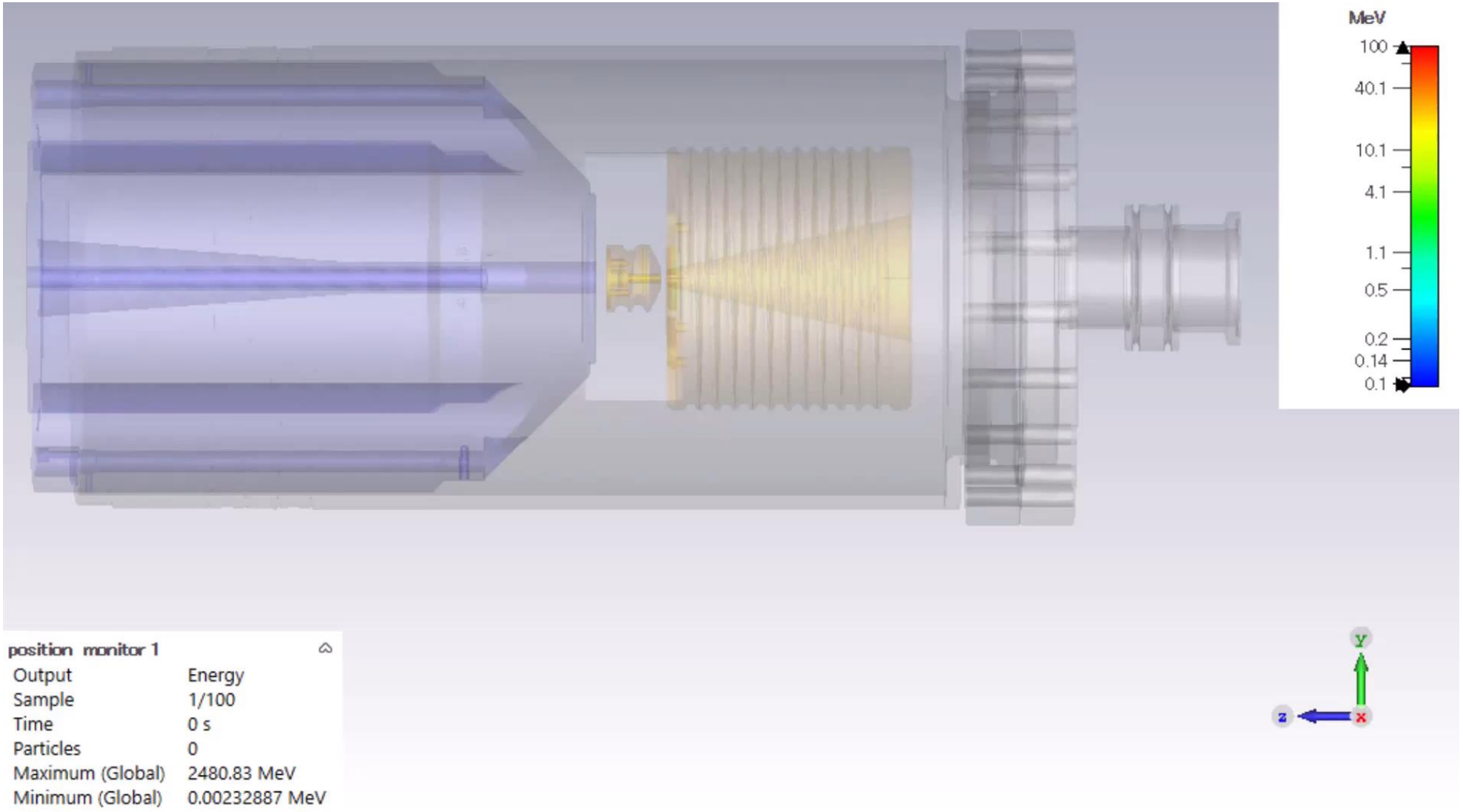
Pulse width dependence



Magnetic field shape is determined by skin depth

It is important to use realistic current waveform for simulation.

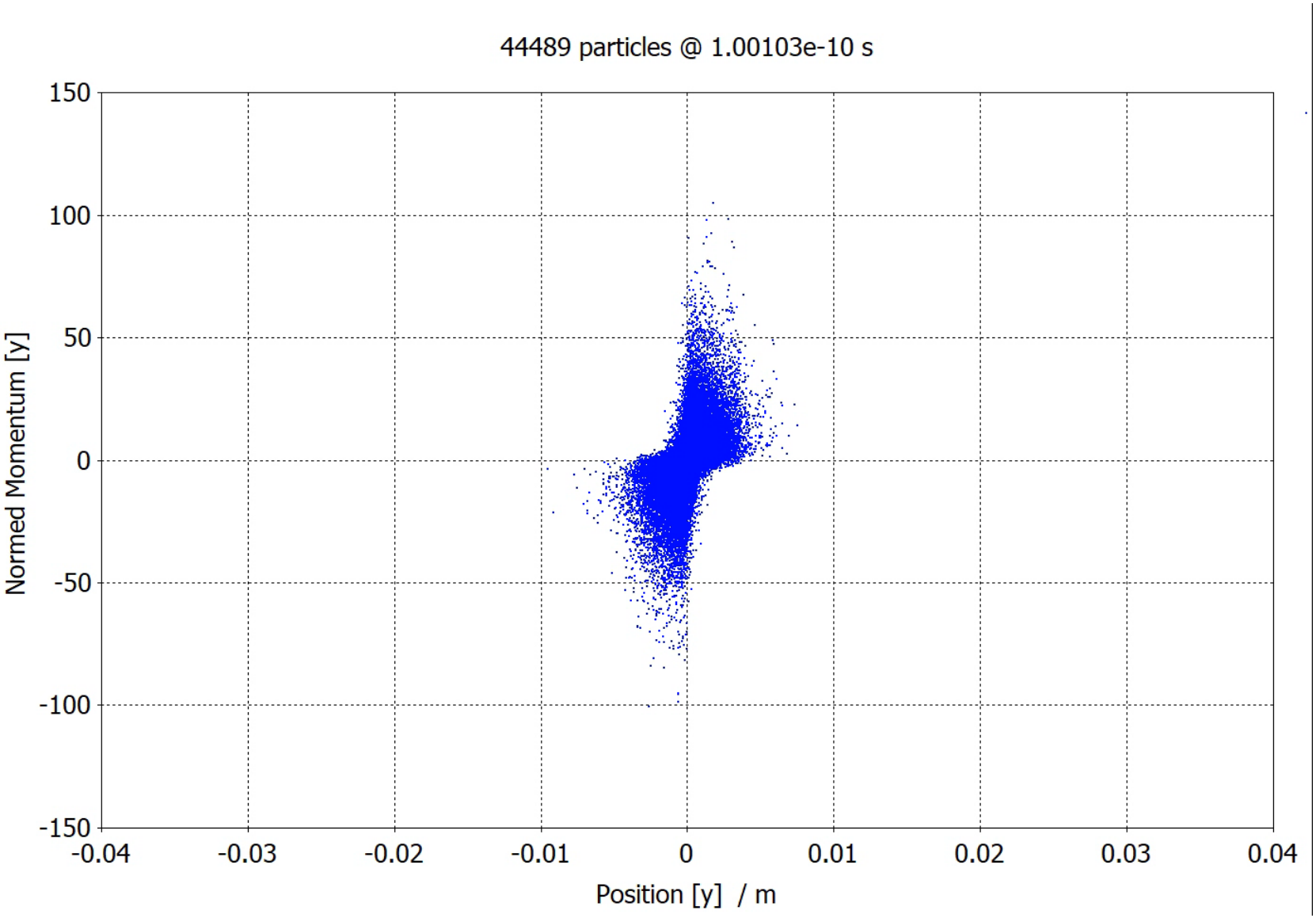
Particle tracking from targe to 1st acc structure



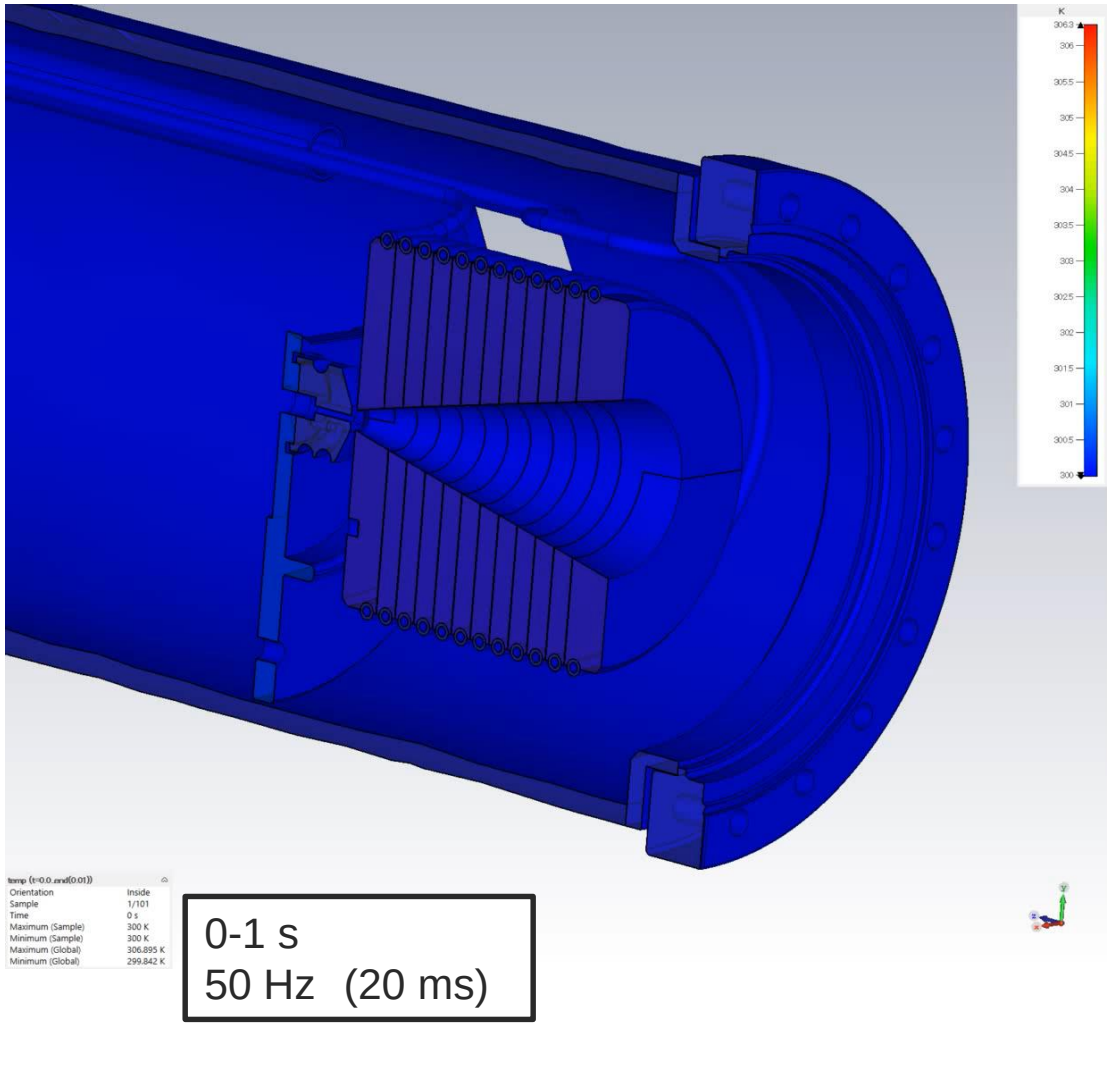
position monitor 1

Output	Energy
Sample	1/100
Time	0 s
Particles	0
Maximum (Global)	2480.83 MeV
Minimum (Global)	0.00232887 MeV

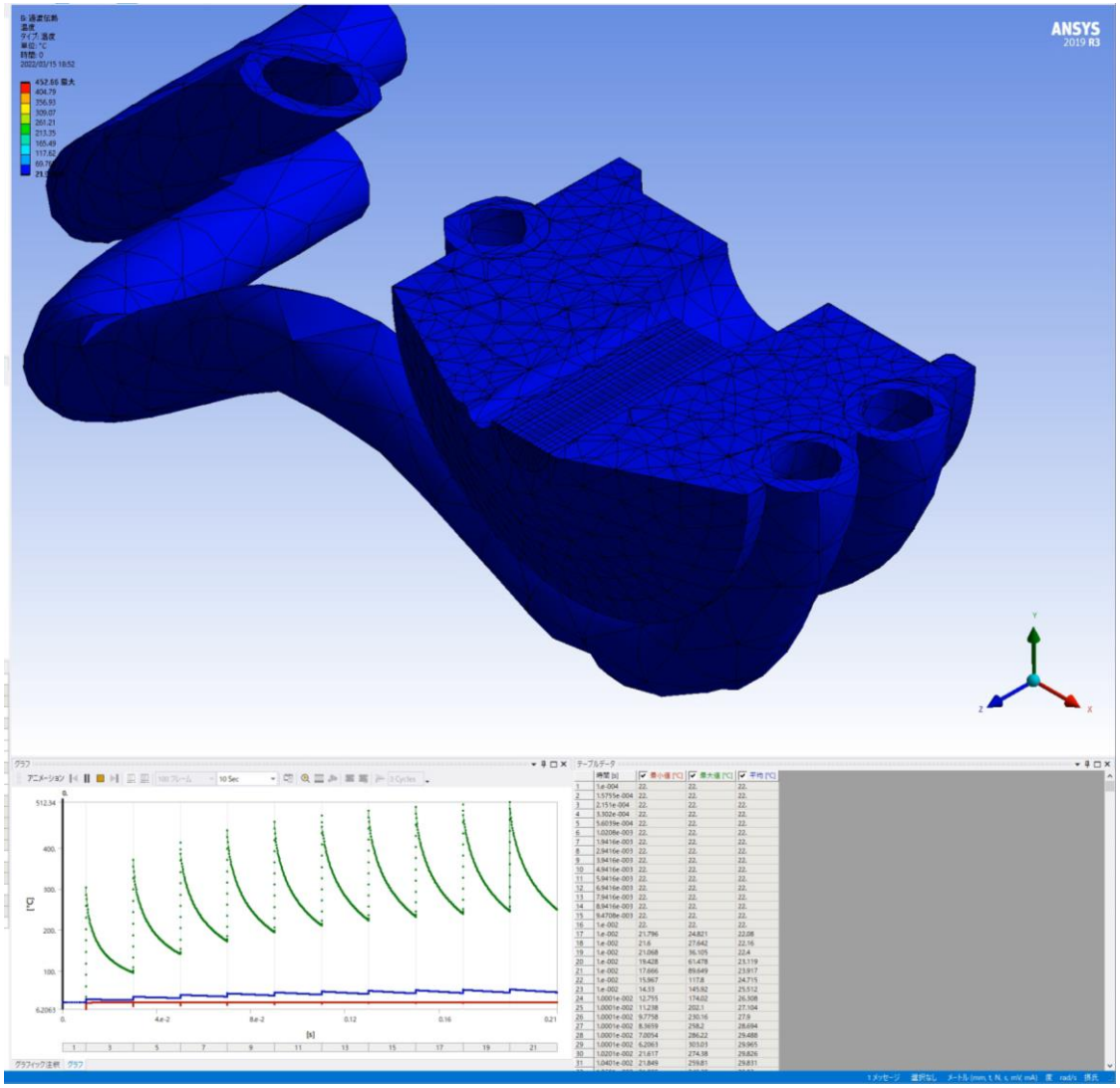
Emittance evalution

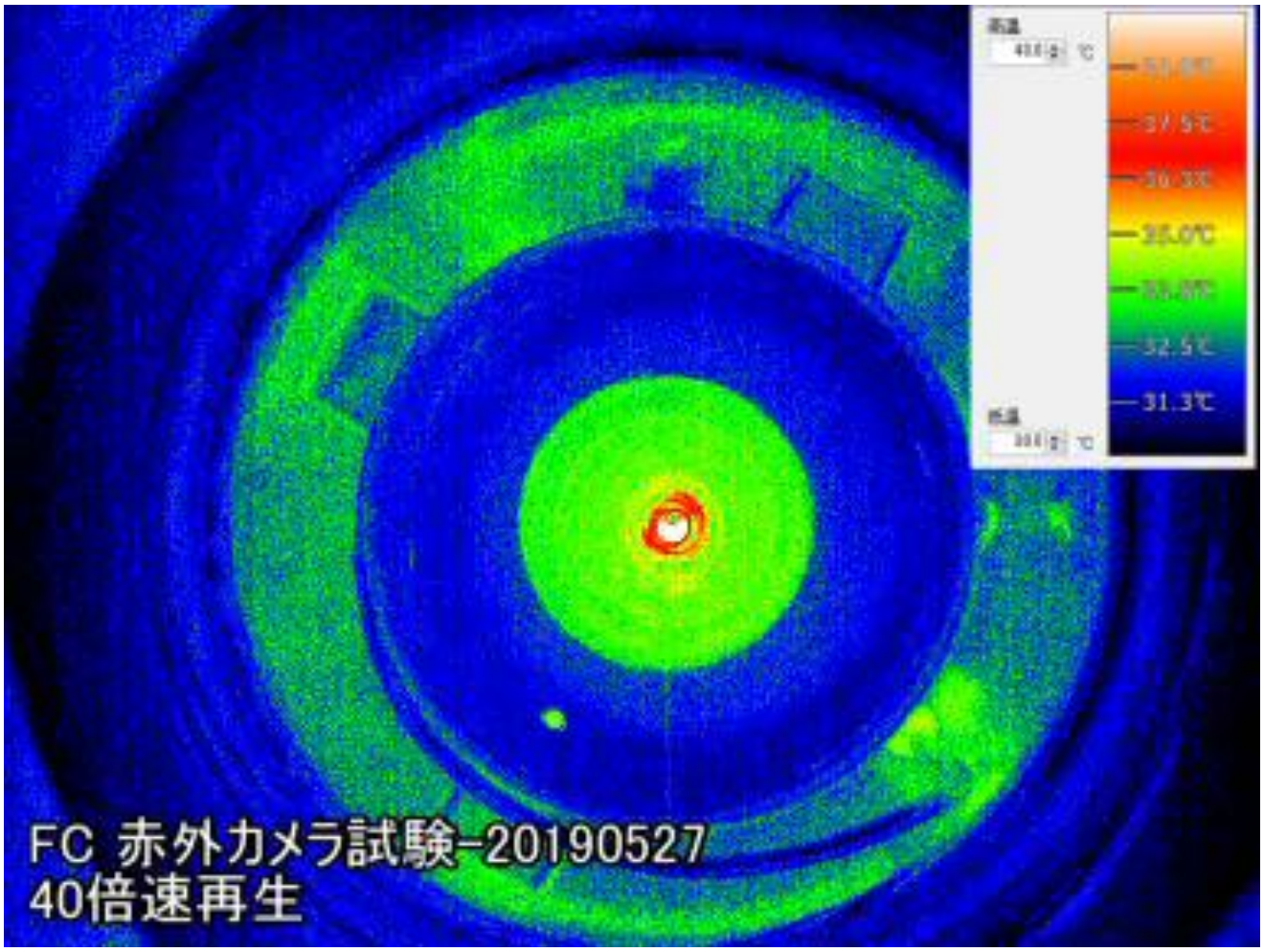


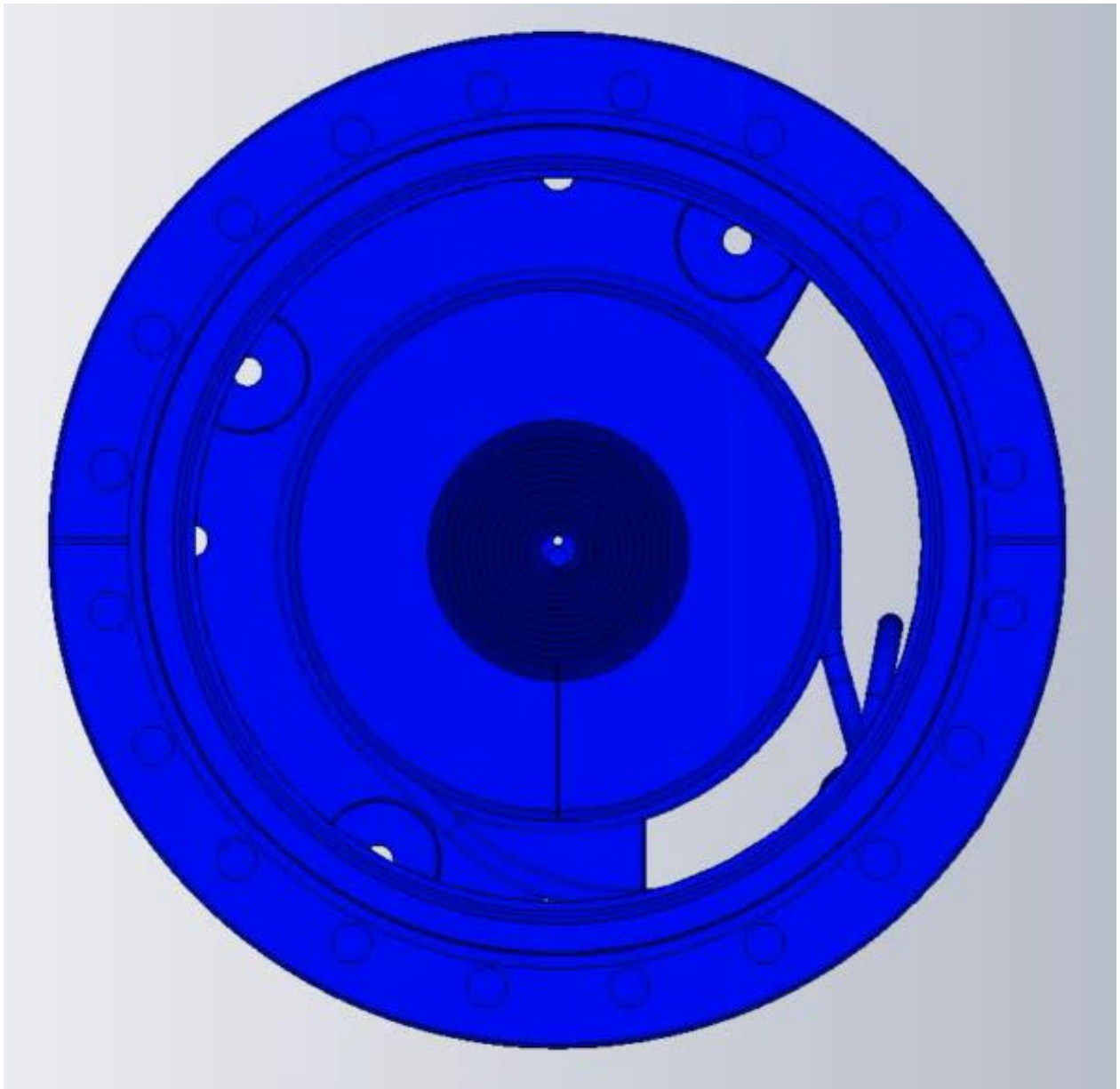
Thermal simulation of FC and target



0-1 s
50 Hz (20 ms)

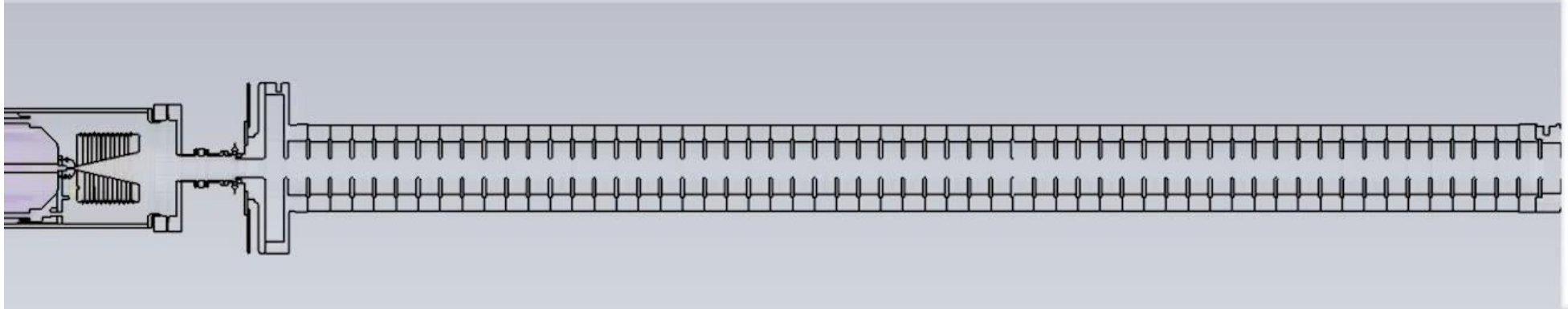



FC 赤外カメラ試験-20190527
40倍速再生

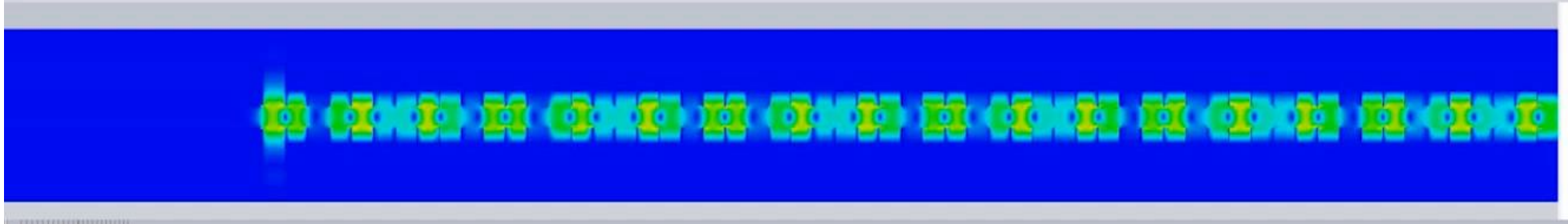


loading

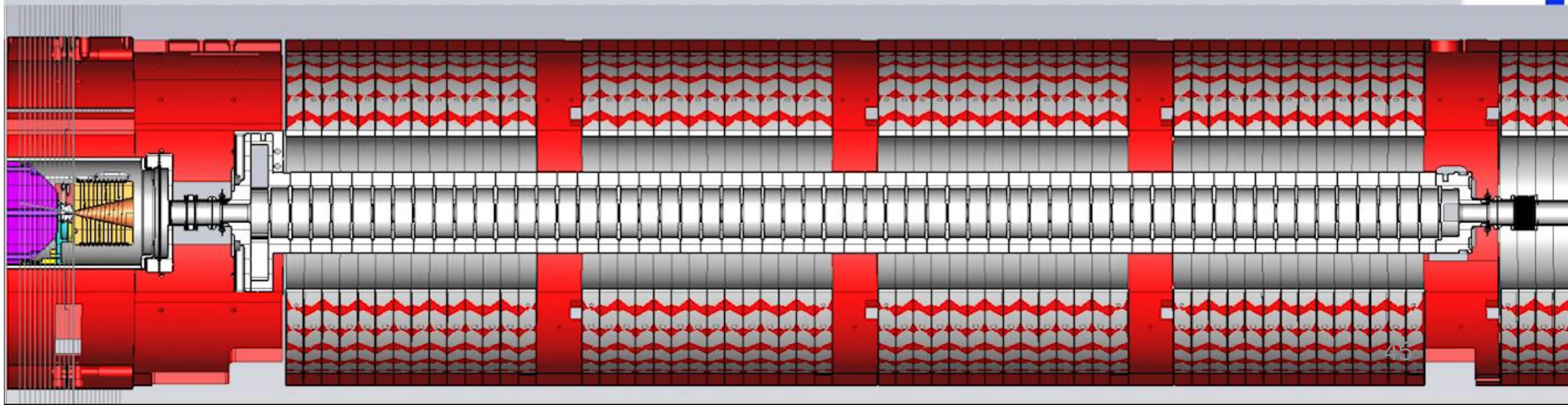
trajectory



Input RF



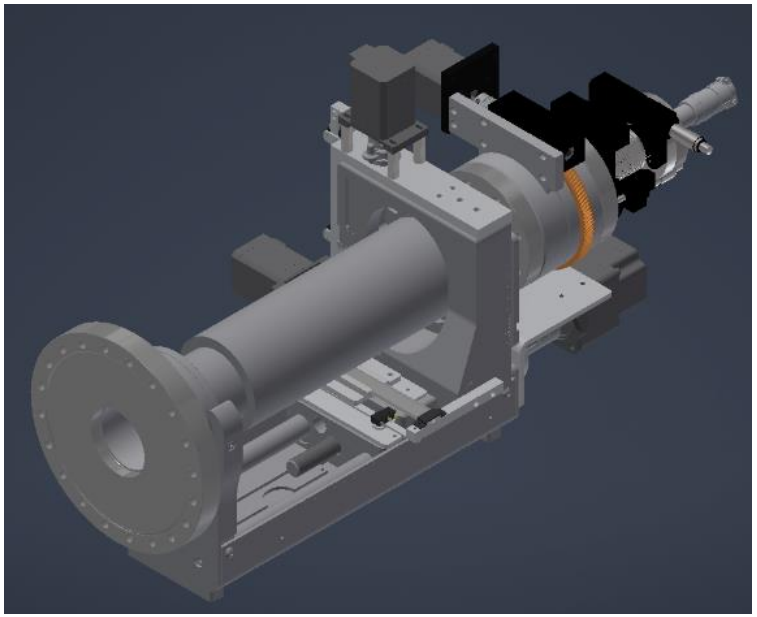
CAD model



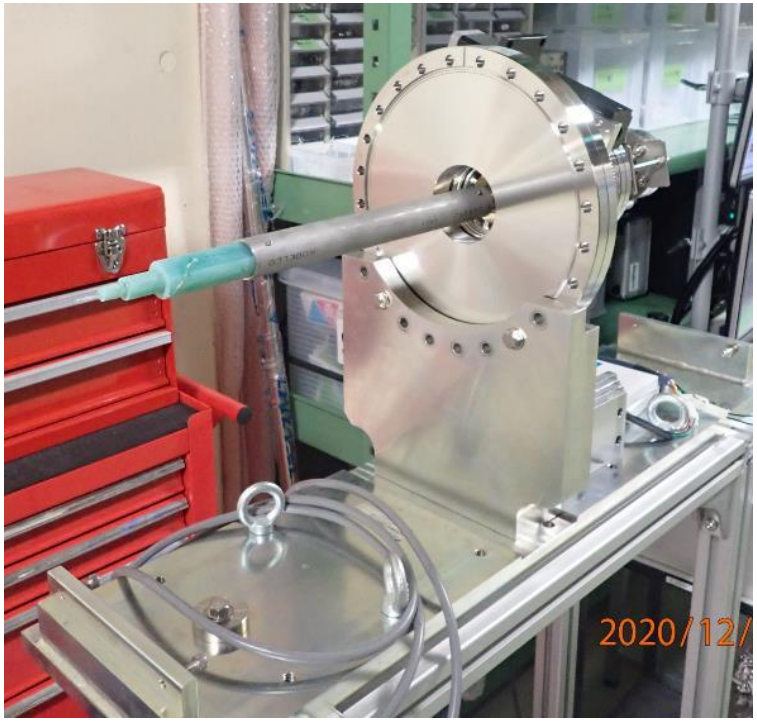
Topics

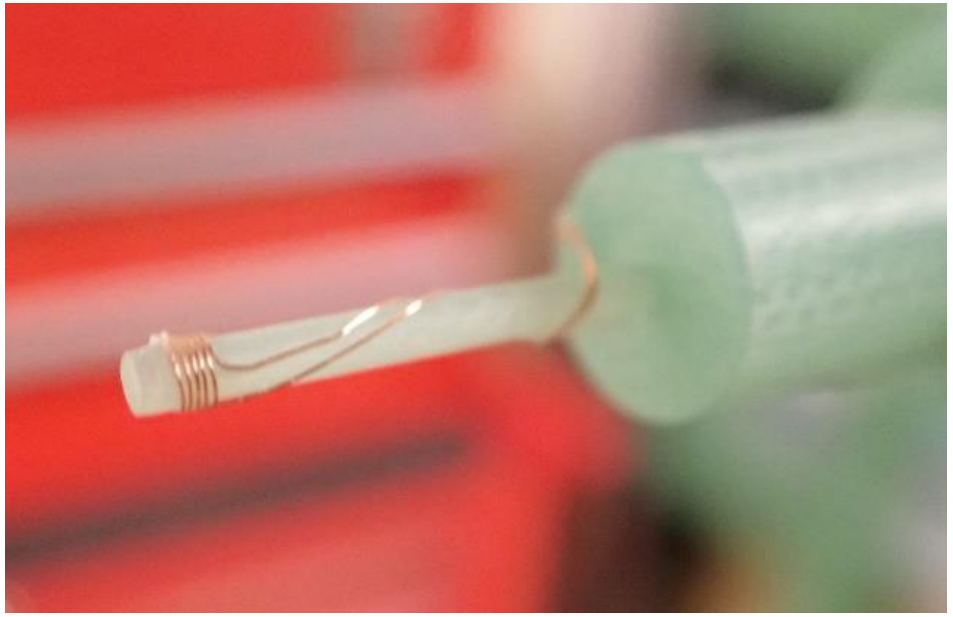
- From 1 nC to 3.5 nC
  - Solve discharge problem of FC
    - Change material of FC head
    - External circuit to reduce voltage
  - Improve beam handling
    - Install steering coils inside the solenoid
- Toward 4 nC and above
  - Shorten distance between FC and 1st acc. Structure
- Another topics
  - Rotating target
  - Full model simulation
  - Magnetic field measurement at test bench
  - Evaluation of W and W-Cu connection

Magnetic field measurement



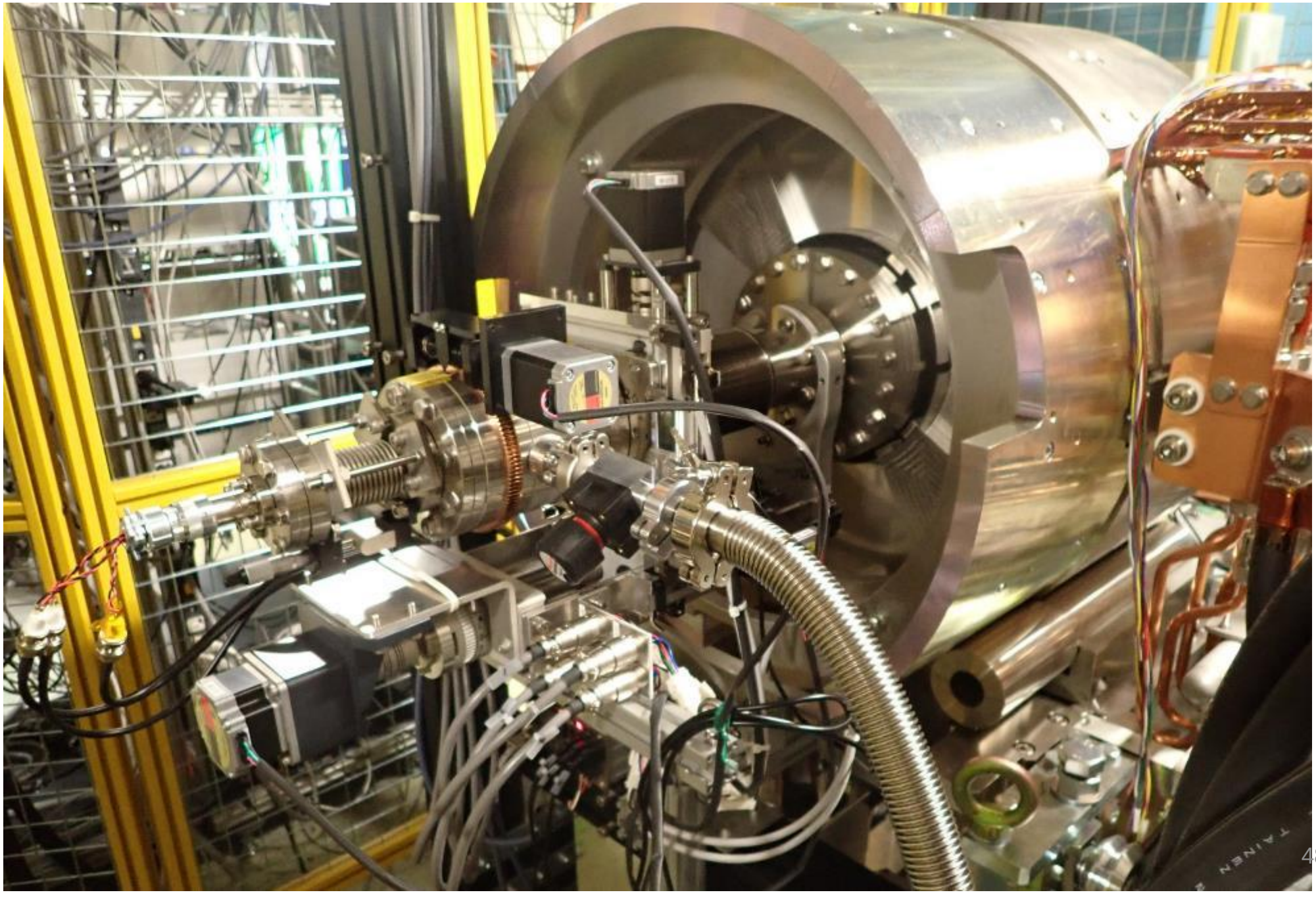
- XYZ stage with motor drive
- Rotary stage with motor drive
- XYZ positions are monitored by linear gauge by 10um precision



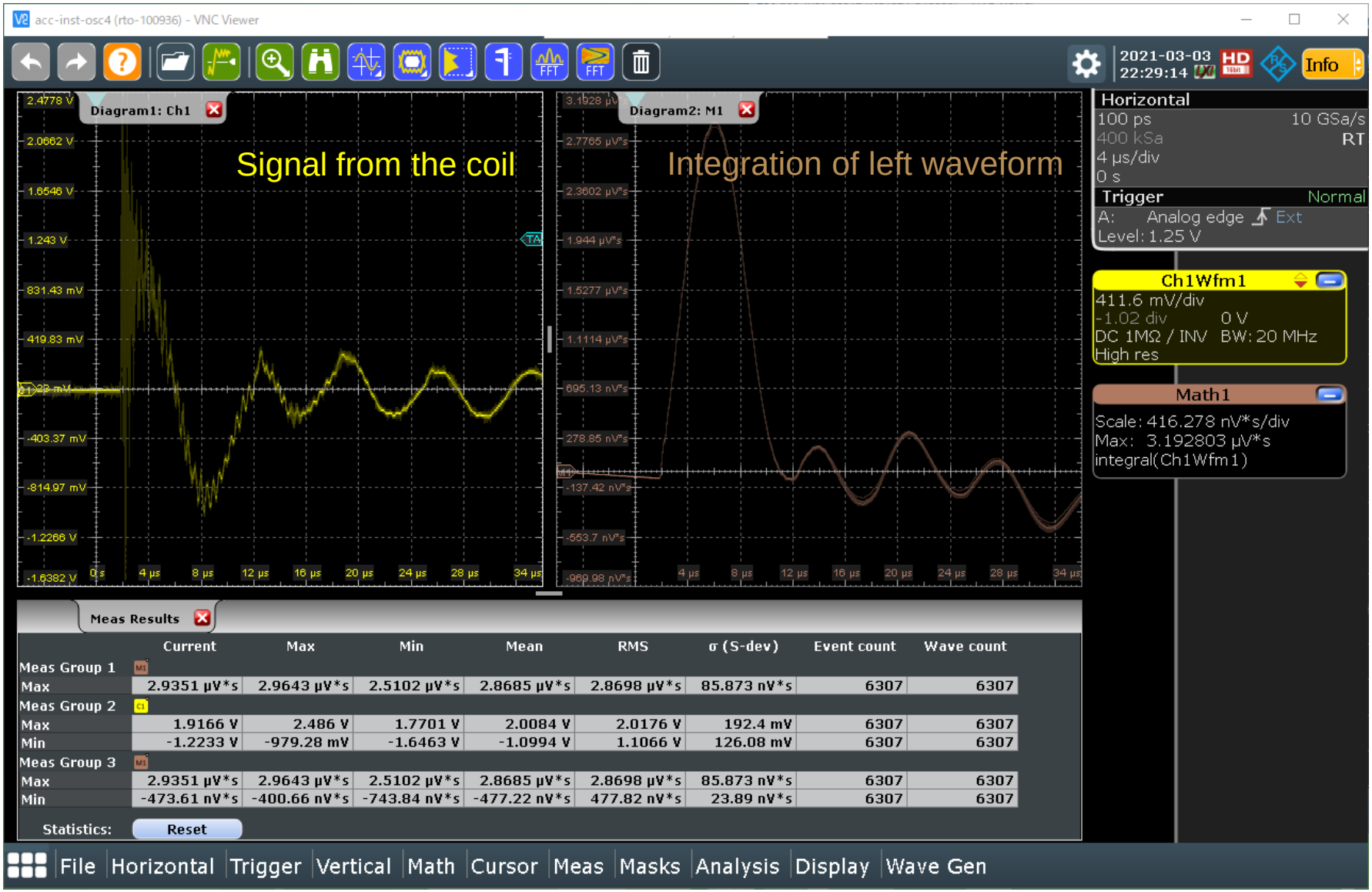


Pick up coil is mounted on FRP rod.

Looking from downstream side with the measurement system attached

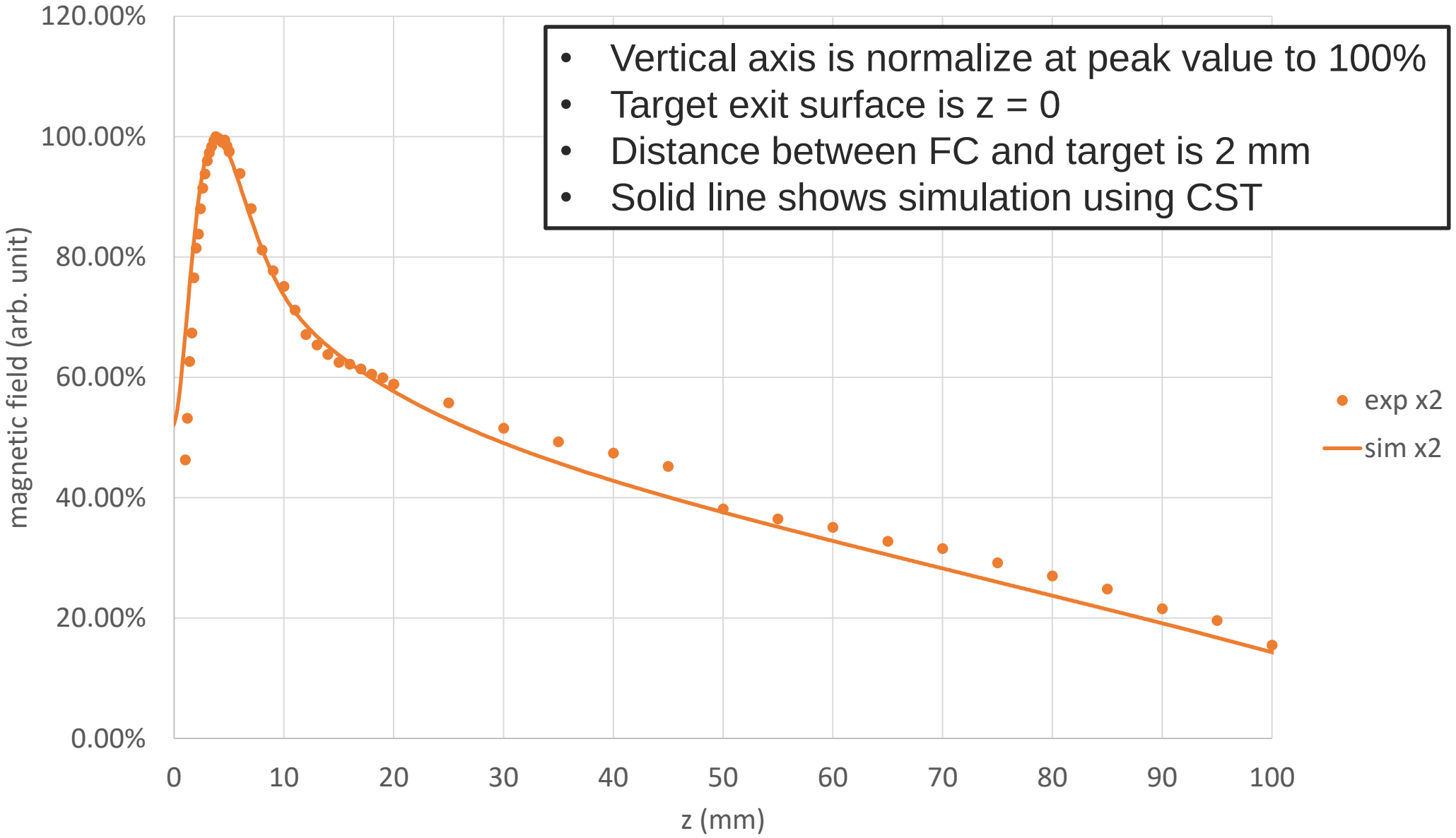


Typical waveform from pick up coil



	Current	Max	Min	Mean	RMS	σ (S-dev)	Event count	Wave count
Meas Group 1								
Max	2.9351 µV*s	2.9643 µV*s	2.5102 µV*s	2.8685 µV*s	2.8698 µV*s	85.873 nV*s	6307	6307
Meas Group 2								
Max	1.9166 V	2.486 V	1.7701 V	2.0084 V	2.0176 V	192.4 mV	6307	6307
Min	-1.2233 V	-979.28 mV	-1.6463 V	-1.0994 V	1.1066 V	126.08 mV	6307	6307
Meas Group 3								
Max	2.9351 µV*s	2.9643 µV*s	2.5102 µV*s	2.8685 µV*s	2.8698 µV*s	85.873 nV*s	6307	6307
Min	-473.61 nV*s	-400.66 nV*s	-743.84 nV*s	-477.22 nV*s	477.82 nV*s	23.89 nV*s	6307	6307

Comparison between simulation and measurement



- Vertical axis is normalize at peak value to 100%
- Target exit surface is z = 0
- Distance between FC and target is 2 mm
- Solid line shows simulation using CST

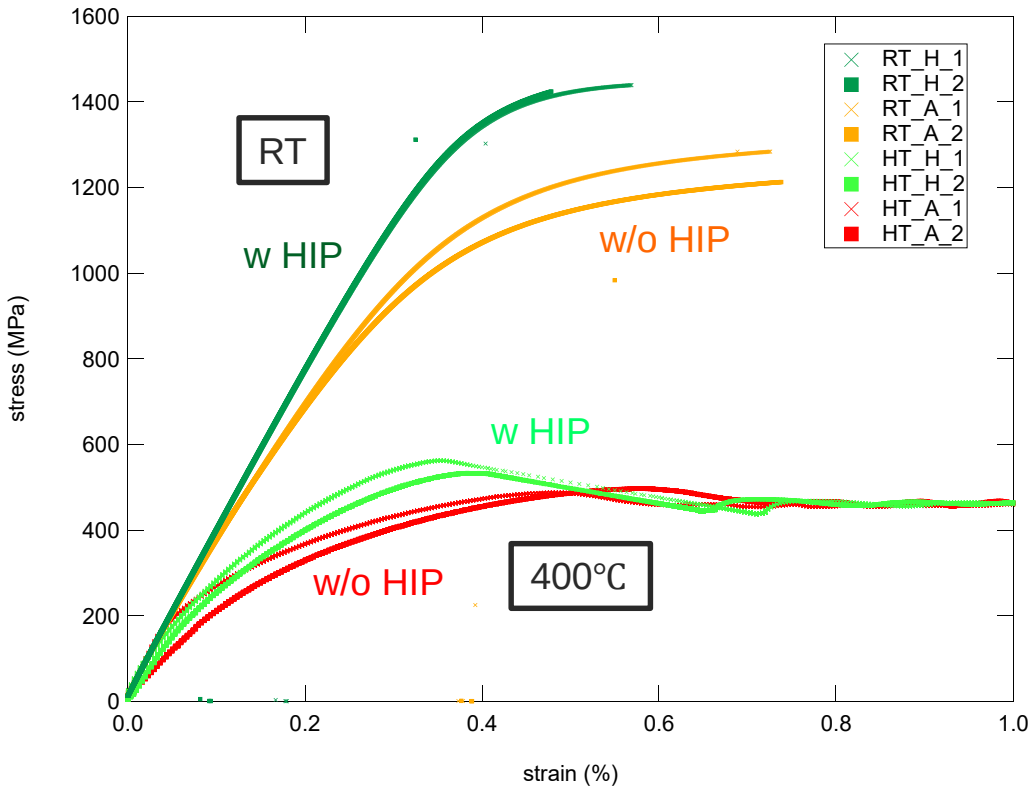
Topics

- From 1 nC to 3.5 nC
  - Solve discharge problem of FC
    - Change material of FC head
    - External circuit to reduce voltage
  - Improve beam handling
    - Install steering coils inside the solenoid
- Toward 4 nC and above
  - Shorten distance between FC and 1st acc. Structure
- Another topics
  - Rotating target
  - Full model simulation
  - Magnetic field measurement at test bench
  - Evaluation of W and W-Cu connection

Evaluation of W and W-Cu connection

Thermal and mechanical evaluation of W and W-Cu connection is important.
Similar tasks are important for plasm facing wall of Fusion facility.
Preparing collaboration with NIFS(National Institute for Fusion Science).

Strain-stress diagram of W



HIP condition : 1050℃, 150 MPa, 2 Hour

40 kV, 300 kW electron beam heating machine @ NIFS

From SuperKEKB to ILC

- There are many common and similar tasks.
  - Experience in SuperKEKB will useful for designing positron source for ILC.
  - Collaboration with many other project like SuperKEKB, FCC, CLIC, CEPC etc. is important.
  - Collaboration with non-accelerating institute is also important.

Target and plan for ILC positron source

- Prepare for manufacturing prototype when pre-lab launched
  - EDR + Drawings + mockup
    - Test and develop critical components
    - Simulation
    - 3D model